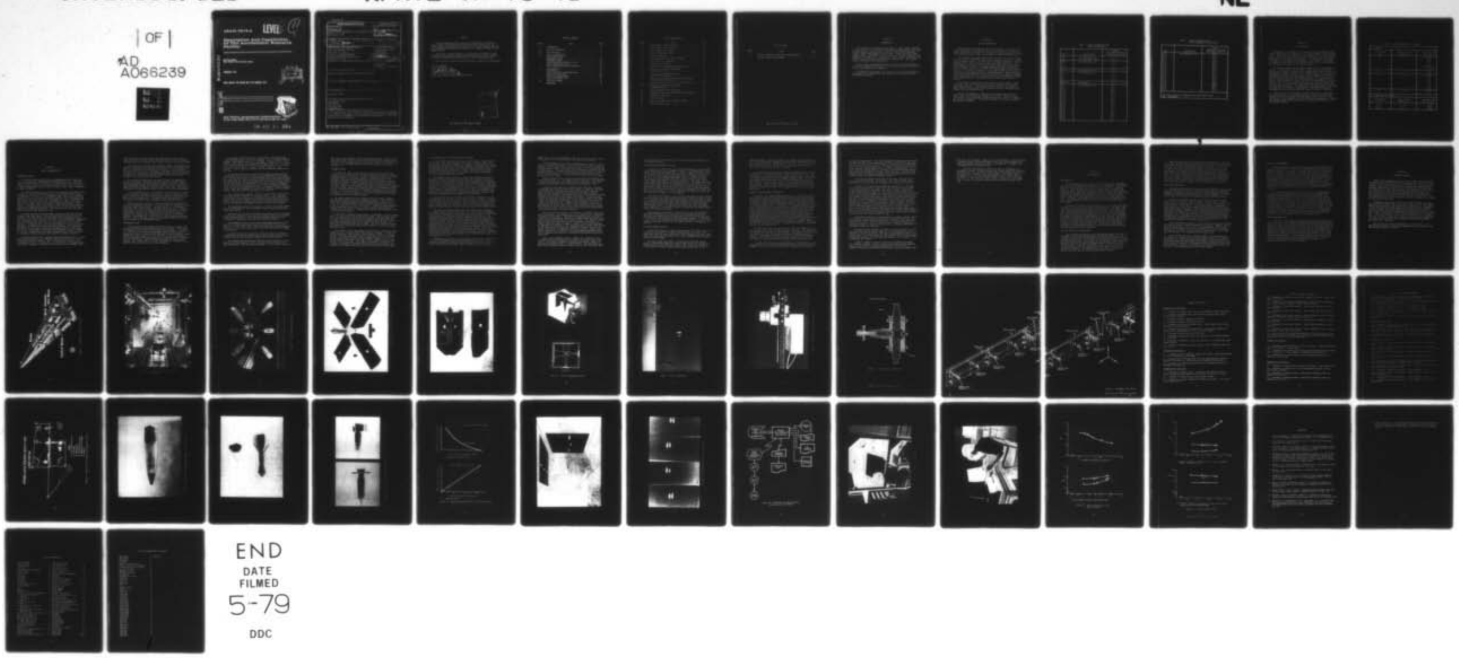
AD-A066 239 AIR FORCE ARMAMENT LAB EGLIN AFB FLA F/G 19/4
DESCRIPTION AND CAPABILITIES OF THE AEROBALLISTIC RESEARCH FACI--ETC(U)
FEB 78 G L WINCHENBACH, D G GALANOS
UNCLASSIFIED AFATL-TR-78-41 NL

| OF |
AD
A066239



END
DATE
FILMED
5-79
DDC

AFATL-TR-78-41

LEVEL II

Description And Capabilities Of The Aeroballistic Research Facility

BALLISTICS BRANCH
GUNS, ROCKETS, AND EXPLOSIVES DIVISION

FEBRUARY 1978

FINAL REPORT FOR PERIOD MAY 1976-JANUARY 1978

Approved for public release; distribution unlimited

Air Force Armament Laboratory

AIR FORCE SYSTEMS COMMAND ★ UNITED STATES AIR FORCE ★ EGLIN AIR FORCE BASE, FLORIDA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
14 AFATL-TR-78-41

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
9

4. TITLE (and Subtitle)
6 DESCRIPTION AND CAPABILITIES OF THE AEROBALLISTIC RESEARCH FACILITY

5. TYPE OF REPORT & PERIOD COVERED
Final Report,
May 1976-January 1978

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
10 G. L. Winchenbach, D. G. Galanos, [redacted] Judith Sullivan Kleist, Billy F. Lucas

8. CONTRACT OR GRANT NUMBER(s)
16 2560 17 07

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Guns, Rockets, and Explosives Division
Air Force Armament Laboratory
Eglin AFB, FL 32542

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Program Element 62602F
JON 25600702

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Armament Laboratory
Armament Development and Test Center
Eglin AFB, FL 32542

12. REPORT DATE
11 February 1978

13. NUMBER OF PAGES
55
12 56p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available in DDC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Free-Flight Testing
Aerodynamics
Ballistic Range
Data Acquistion
Instrumentation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A description of the Aeroballistic Research Facility and the instrumentation systems are presented. Also, a discussion of the facilities capabilities with respect to instrumentation, data reduction, test conditions, and measurement precision is provided.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

JOB

400 936

PREFACE

The work documented in this report was performed by the Ballistics Branch (DLDL), Guns, Rockets and Explosives Division (DLD), of the Air Force Armament Laboratory (AFATL), Eglin Air Force Base, Florida. The work was accomplished intermittently from May 1976 to January 1978 under Project Number 25600702.

This report has been reviewed by the Information Officer (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets, and Explosives Division

(The reverse of this page is blank)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

(The reverse of this page is blank)

SECTION I

INTRODUCTION

The Aeroballistic Research Facility (ARF) is a free-flight aerodynamic testing facility. It is a part of the Ballistics Branch (DLDL), Guns, Rockets and Explosives Division (DLD) of the Air Force Armament Laboratory (AFATL), Armament Development and Test Center (ADTC), Air Force Systems Command (AFSC). Construction of the facility was initiated in May 1972 and completed in December 1973. Installation of the facility's instrumentation began in January 1974 and was completed in November 1975. The facility became fully operational in March 1976.

This facility is designed primarily for exterior ballistic tests of projectiles, although other types of tests such as air-to-air missiles and air-to-ground munitions are conducted.

The purpose of this report is to discuss the facility's capabilities with respect to instrumentation, data reduction, test conditions, and measurement precision.

SECTION II

FACILITY DESCRIPTION

The Aeroballistic Research Facility is an enclosed, instrumented, concrete structure used to examine the exterior ballistics of various free-flight projectiles (See Figure 1A). The facility contains a gun room, control room, model measurements room, blast chamber, and the instrumented range.

The 207-meter instrumented length of the range has a 3.66-meter square cross section for the first 69-meters and a 4.88-meter square cross section for the remaining length. The range has 131 locations available as instrumentation sites. Each location has a physical separation of 1.52-meters and presently 50 of the sites are used to house fully instrumented orthogonal shadowgraph stations. The maximum shadowgraph window, an imaginary circle in which a projectile in flight will cast a shadow on both reflective screens is 2.13 meters in diameter. A laser lighted photographic station is located in the uprange end of the instrumented range. This photographic station yields four orthogonal photographs, permitting a complete 360-degree view of the projectile as it passes the station on its downrange trajectory. A view looking down the instrumented portion of the range is shown in Figure 1B.

Four flash X-ray heads are located within the blast chamber. These flash X-ray heads can be combined to form four in-line or two orthogonal radiographic stations. These stations provide inspection photographs of model integrity and the model-sabot separation process as the model-sabot package exits the launcher muzzle.

All the instrumentation systems have been designed and installed in such a manner as to permit the stations to be movable. Therefore, any station can be moved to another instrumentation site in order to accommodate special test requirements. The present locations of the various stations are tabulated in Table 1.

TABLE 1. PRESENT LOCATIONS OF THE RANGE INSTRUMENTATION

Unit	Description *	Nominal Longitudinal Distance From Range Origin (m)
X-Ray 1	Two orthogonal views	-8 to -14
X-Ray 2	(or four single plane)	-6 to -12
SG** 1	Two orthogonal views	2.0
SG 2		3.5
SG 3		5.0
SG 4		8.1
Laser 1	Four orthogonal views	9.6
SG 5	Two orthogonal views	14.2
SG 6		17.2
SG 7		20.3
SG 8		21.8
SG 9		23.3
Multi SG 1	Eight photos	26.4
SG 10	Two orthogonal views	29.4
SG 11		35.5
SG 12		38.6
SG 13		41.6
SG 14		44.7
SG 15		47.7
SG 16		52.3
SG 17		55.3
SG 18		58.4
SG 19		64.4
SG 20		67.5
SG 21		70.5
SG 22		73.7
SG 23		76.6
SG 24		79.6
SG 25		82.7
SG 26		84.2
SG 27		88.8
SG 28		93.4
SG 29		98.0

TABLE 1. PRESENT LOCATIONS OF THE RANGE INSTRUMENTATION (CONCLUDED)

Unit	Description*	Nominal Longitudinal Distance From Range Origin (m)
SG 30	Two orthogonal views	102.5
SG 31		107.1
SG 32		116.3
SG 33		120.9
SG 34		125.4
SG 35		130.0
SG 36		134.6
SG 37		139.2
SG 38		143.7
SG 39		148.3
SG 40		152.9
SG 41		157.5
SG 42		162.0
SG 43		166.6
SG 44		171.2
SG 45		178.8
SG 46		183.4
SG 47		188.0
SG 48		192.5
SG 49		197.1
SG 50		201.7

*All units yield two orthogonal views except where noted.
**SG = Shadowgraph

SECTION III

TEST CONDITIONS

The range is an atmospheric test facility where the temperature and relative humidity are controlled to 22 ± 1°C and less than 50 percent respectively. The facility is capable of testing varied model sizes and configurations. Some of the models and projectiles previously tested or presently scheduled for testing are shown in Figure 2. As evidenced by this figure both symmetric and asymmetric configurations can be tested. The physical measurements of the models (mass, inertias, centers-of-mass and dimensions) are obtained on site, prior to testing (Reference 1).

The launchers and barrels presently available for use are tabulated in Table 2. As can be seen from this table a wide variety of barrels and launchers are presently available; these include powder guns and compressed air launchers. However, facility users frequently wish to use special or developmental launchers and these can be readily adapted to the system. For models requiring sabots for the launching process (Figure 3), the developmental testing of the model-sabot package normally is accomplished on an open air range (Reference 2) prior to testing in the Aeroballistic Research Facility. During this development phase both high speed photography and witness panels are used to analyze the model-sabot separation process and resulting model trajectory. By conducting the development phase on the open air range the risk of damage or destruction to the more sophisticated instrumentation within the Aeroballistic Research Facility is minimized.

The test velocities attainable within the facility are a function of the launcher used for a particular test item. Tests can be conducted at subsonic, transonic, and supersonic Mach numbers (M = 0.4 to 6). Since the facility is an atomospheric test facility and the temperature is controlled, Reynolds number can be varied only by varying model scale for a particular test velocity.

TABLE 2. AVAILABLE BARRELS AND LAUNCHERS

A. BARRELS		
Bore Diameter (mm)	Range of Barrel Lengths (m)	Available Twist Rates (deg/cm)
20	1.2 - 1.5	Smooth 4.43 6.15 7.09 11.07 Various Gain Twists
25	2.13	4.76 6.56
30	1.3 - 2.6	Smooth 2.95 5.90 6.04 7.09 7.87 8.86 11.81
40	2.4 - 3.0	Smooth 7.1
B. Compressed Gas Launchers		
Bore Diameter (mm)	Range of Barrel Lengths (m)	Available Twist Rates (deg/cm)
152.4	3.7, 4.8	Smooth
203.2	4.8	Smooth
355.6	4.3	Smooth

SECTION IV

RANGE INSTRUMENTATION

SHADOWGRAPH SYSTEM

As previously mentioned, the basic instrumentation in the range consists of 50 dual plane orthogonal spark shadowgraph stations. Each shadowgraph station consists of two cameras, two spark sources, two reflective screens, a power supply, and an infrared (IR) detection system. A sketch of a typical shadowgraph station is shown in Figure 4 and a typical shadowgram is shown in Figure 5.

The shadowgraph camera body consists of an aluminum casting with mating surfaces for lens, film back holder, spark gap housing and three flanges for mounting. The lens is a 17.8-centimeter focal length F/2.5 Aero Ektar and the back is a 10.2 by 12.7 centimeter Graphlok. The solenoid operated shutter is a two leaf capping type. Internally the camera is equipped with four fiducial projectors which are illuminated by a single 28-volt direct current (Vdc) lamp. Light is piped to each fiducial projector by fiber optics. In addition, there are 12 numeric light emitting diodes (LEDs) projected at 0.5 magnification onto the edge of the film for recording spark function time and other fixed data. The film used is 10.2 by 12.7 centimeters thick base Kodak Royal X-Pan film.

The spark gap uses a Tobe Deutschman coaxial disc capacitor with the cathode, anode, and trigger of the spark gap mounted in the center of the capacitor. The light emerges axially through a 0.10-centimeter orifice. The capacitor is rated at 20 kilovolts (kV), 0.1 microfarads (MF), capacitance and 1.0 nanohenry (NH) inductance. The rise time of the spark is approximately 0.1 microsecond (μsec), with a total duration of 0.2 to 0.3 μsec. The spark is triggered with a Tobe Deutschman model TG-2 high voltage pulse generator. The capacitor and the spark gap are mounted in an insulated housing and this in turn is attached to the mating surface at the rear of the camera. A photograph of the camera-spark assembly is shown in Figure 6. A cross sectional view of the spark gap showing the relative locations of the anode, cathode and coaxial-disk capacitor is shown in Figure 7.

The power supply has two, standard, high voltage modules, one (-7.5 kV) charges the high voltage pulse generators and the other (0-20 kV) is used for charging the main capacitor. These are mounted on a chassis along with dumping resistors, a panel meter, a variac and the low voltage trigger. The chassis is mounted in a wheeled relay rack which also accommodates the

chronograph chassis and the other camera and detector screen controls. There is one rack for each station, and there are provisions for remotely controlling the racks from the control console located in the control room.

The reflective screen material is Minnesota Mining and Manufacturing Company's high gain reflective sheeting laminate #6711. The average diameter of an individual lens element in the screen is 0.0051 centimeter. The screen sizes are 1.22 by 2.44 meters in the upper portion of the facility and 1.22 by 3.66 meters in the downrange portion. The screen material is mounted on a polyurethane-aluminum sandwich backing which in turn is mounted to the facility walls and ceiling.

An Infrared (IR) detection system used to detect the approach of ballistic projectiles and trigger the spark sources is located approximately 15 centimeters uprange of the wall mounted reflective screens at each shadowgraph station. The detection system consists of an IR transmitter and detector mounted on opposite walls of the range. Each unit is 2.44 meters in length and has a cross section of 5.08 by 6.99 centimeters.

The IR transmitter has a 1.59-centimeter slit down the entire length of its front face. Behind the slit there is a piece of Corning filter glass to block out the visible light from the lumeline incandescent lamps that act as the IR generator. The lumeline lamps are energized by a low ripple 150 Vdc power supply contained in the chronograph chassis.

The detector unit consists of 24, Motorola MRD 300, silicon phototransistors connected in parallel. They are spaced 10.2 centimeters apart along the length of the detector. The detector has a 0.32-centimeter split down its 2.44-meter front. The photo-transistors have a 20-degree beam width. Due to the fan-shapedcoverage area of one detector, the detection beams overlap. The combined output of the photo-transistors is amplified by a preamp which is mounted in the center of the detector assembly. The preamp used is a Fairchild 715 high frequency operational amplifier. The 15-Vdc power supply for the preamp and the photo-transistors is mounted in the chronograph chassis.

CHRONOGRAPH SYSTEM

The chronograph system provides the required times of flight as the projectile traverses the instrumented portion of the range. Event times, corresponding to each spark source discharge are obtained to a resolution of ± 0.01 μsec by electronic chronographs located at each of the 50 shadowgraph stations. Experience has indicated that both orthogonal sparks normally discharge within 0.3 μsec of each other. The chronographs at each station operate under the control of the sequencer and in conjunction with the velocity data system, IR detection system, and the spark gap assembly. The timing system in all the chronographs is synchronized to a master 10 MHz clock located in the control console.

The sequencer provides the pulses listed below to the chronographs at the following times in the firing sequence: (1) -3.5 seconds -solenoid operated camera shutters open (2) -2.5 seconds - fiducials on (3) -2.0 seconds - clear (Resets all chronograph counters to zero) (4) -1.5 seconds-start (counters synchronized to the master 10 MHz clock) (5) -1.0 second - Fire (gun is fired) (6) +3.5 seconds - shutters closed (7) + 10.5 seconds - strobe transfers accumlated time in chronograph counters onto the film.

The velocity data system, located in the control console, provides a quick look velocity profile of the projectile immediately after launch. This system receives pulses from the chronographs as the projectile passes their respective IR detectors and then computes and displays the velocities on a paper printout. The IR screen pulse is also used to initiate a delay circuit contained in the chronographs. This delay is used to compensate for the time it takes the projectile to pass the IR detector and center itself in front of the reflective screens. The amount of delay is manually set by a three digit thumbwheel located on the front panel of the control console. The delay can be varied from 0.1 to 9.99 msec.

After the delay has elapsed, a 12-volt, 50-μsec pulse is sent to the low voltage pulser located in the spark gap assembly. This same pulse is used by all other stations as a lockout pulse to prohibit them from prefiring due to the triggered station spark discharge during the 50 μsec period. This helps to prevent adjacent station interference in the presence of the high noise environment caused by the spark gap discharges.

The chronograph counters are stopped by a light sensing diode located near the spark gap port. Each chronograph counts elapsed time from the common start pulse.

Stations at the far end of the tunnel will take up to 3.3 μsec longer to receive the common start pulse due to the lumped signal delays inherent in the connecting cables. This time delay has been measured at each station and is compensated for in the data reduction programs.

Four thumbwheel digits located on the chronograph chassis are available for fixed shot identification data to be placed on the film (See Figure 5). A fifth digit which is hard wired internally identifies whether the film was from a wall or pit camera. The first four digits are common to both cameras.

A switch to select the sensitivity of the IR system is provided to accomodate the various size projectiles that may be tested in the tunnel. In the HI position a projectile as small as BB is easily detected.

The simulate/high voltage pulse (HVP) switch will normally be in the HVP position which indicates that the counters will be stopped by the high voltage pulses from the spark gap assembly. In the simulate position

the counters are stopped by a pulse that would normally be routed to the spark gap assembly. With the switch in this position the spark gap assembly will not be triggered but the velocity pulse will be sent to the velocity data system for computation of the velocity between two adjacent stations.

ALIGNMENT SYSTEM

In ballistic range testing, the time history of the position and orientation of an object in free-flight is precisely determined at various locations along its trajectory. In order to obtain this precise position - orientation history an accurate reference system must be used. The reference system used in the Aeroballistic Research Facility consists of Kevlar® fiber bundles (henceforth called wires) with reference beads positioned at precisely ± 45.72 centimeters about 1.52-meter centers over its entire length. Two Kevlar® wires are strung in front of the wall-mounted reflective screens and two are strung below the ceiling-mounted reflective screens. With this positioning, two beads on each wire are in the field of view of each camera (Figure 5). The range coordinates of each bead are well known. The relative positions of the wires and therefore the beads are maintained with the alignment system.

The major components of the alignment system are shown in Figure 8. Numbered callouts are explained in legend for Figure 8. They include: four overhead endpoint trusses labelled endpoint truss position 1, 2, 3, and 4, three overhead midpoint trusses labelled midpoint sag position 1, 2, and 3, a water level system, translators, a catenary movement detection system (henceforth called sensors), a master catenary and the Kevlar® catenary wires with beads. A complete description of the alignment system is presented in Reference 3.

A right-handed coordinate system, where x is downrange, y is cross-range, and z is vertical, has been defined for the range. The crossrange coordinate is defined with the use of a master catenary which determines the x-z plane. The vertical coordinate is defined by the water level system, using the equipotential lines of the earth's gravity as a basis. The water level system determines the x-y plane. The first bead on the lower wall catenary is arbitrarily chosen as the origin (0, 0, 0) of the range reference system.

Each catenary wire is approximately 70 meters long. Therefore, three lengths of wire are needed to span the length of the range. As there are four catenary wires, the reference system requires a total of 12 lengths of wire. The three consecutive spans of wire comprising one of the four catenaries are coupled together by the alignment system so as to act as one 207.26 meters long wire. Each end of the 12 lengths of wire is held in place with a flat clamp. This clamp is attached to a translator, or a series of translators, depending upon the wire being considered. The translators are teamed with a series of sensors which detect any movement

of the catenary wires from their preset positions.

Located within each endpoint truss is an Invar® bar, a low expansion nickel alloy, with calibration marks precisely 1.52 meters apart. This bar positions the ceiling catenaries a constant, arbitrary distance from, and parallel to, the plane of the master catenary. The upper wall catenary at each endpoint truss position is initially placed parallel to, but some arbitrary distance from, the x-z plane. The lower wall catenary is placed in a position parallel to the plane of the master catenary and in plane with the upper wall catenary.

For endpoint truss positions 1, 3 and 4, one translator located at the end of each truss accounts for any translator movement necessary to keep the two ceiling catenaries and the upper wall catenary in alignment. A plumb line is dropped from a bracket in each endpoint truss to the floor. As the truss is repositioned, the plumb line moves. When this plumb line movement is sensed, a translator moves the lower wall catenary, maintaining the catenary a constant distance from, and parallel to, the plane of the master catenary. Endpoint truss position 2 is similar to endpoint truss positions 1, 3, and 4, except a separate translator moves the upper wall catenary corresponding to any movement of the plumb line.

A water level system, corrected for the earth's curvature, is used to define the zero reference for the vertical range coordinate. Polyvinyl Chloride (PVC) tubes (2.54 centimeter ID) are mounted on one wall parallel to the plane of the master catenary. This tube extends the length of the range. Sections are also run parallel to the crossrange direction, perpendicular to the master catenary, inside all endpoint and midpoint trusses.

The plumb line dropped from the truss of endpoint truss position 2 has a marker glued on it near the floor. This marker-sensor combination is preset in some arbitrary initial position. Two sensors, attached to the truss, monitor any change in water level for span 1 and span 2. Any change from the preset position causes a pump to adjust the water level by adding or removing water. The water level at its preset position, defines an x-y plane. With the use of a second marker on the plumb line, a translator at one end of the truss maintains the end of the truss in a plane parallel to the plane of the water level system. Another translator, located at the other end of the truss, maintains the whole truss in a plane parallel to the plane defined by the water level system. A third and fourth vertical translator, located at the lower wall catenary and upper wall catenary maintains those catenaries in positions parallel to the plane of the water level system when the motion of a third and fourth marker on the plumb line is sensed.

Endpoint truss positions 1, 3, and 4 have one translator on either end of the overhead endpoint truss which maintains the truss, the ceiling catenaries, and the attached upper wall catenary in a plane parallel to the x-y plane of the water level. When any motion of a marker on the

plumb line is sensed, the translator moves the lower wall catenary into a plane parallel to the plane defined by the water level system.

Three translators are located at midpoint sag positions 1, 2, and 3. The first translator maintains a vertical Invar® bar a constant arbitrary distance from the plane of the water level system. This bar positions the attached sensors so they can measure the midpoint sag of the upper and lower wall catenaries. Two more translators are located along the ceiling to maintain the position of the sensors which measure the midpoint sag of the two ceiling catenaries, a constant arbitrary distance from the plane of the water level system.

With the catenary wires in their preset positions the midpoint sag sensor positions are set. The midpoint sag of each wire is then monitored in order to guarantee the same catenary curve at all times. This then maintains all reference beads in their preset downrange positions.

A sensor on the plumb line at endpoint truss Position 1 triggers a translator which keeps the lower wall catenary in plane with the upper three catenaries. A translator located at the far end of the truss keeps the truss perpendicular to the plane of the master catenary. Endpoint truss Position 2 contains the translators described above and the translators which work off the midpoint sag sensors. At each ceiling catenary position and each wall catenary position, catenaries from spans 1 and 2 are coupled by a translator. These translators move both span 1 and 2 wires simultaneously. Endpoint truss positions 3 and 4 are identical to the above. They consist of the translators which work off the midpoint sag position and 2 and 3 sensors respectively, and a translator at the far end of the truss which retains the truss perpendicular to the plane defined by the master catenary.

Once in the preset position, the translators at endpoint truss position 1 do not move. The midpoint sag of each catenary wire is monitored at midpoint sag position 1. Any deviation from the preset sag sends a signal to the corresponding translator at endpoint truss position 2 which moves to adjust the tension in the catenary wires. This change in translator position causes the sag position at midpoint sag position 2 to change. When this change is sensed, a signal is sent to the translator at endpoint truss position 3. This translator moves to adjust the tension in the catenary wire and therefore, maintains the preset sag positions. Finally, the sensors at midpoint sag position 3 detect a change in the preset catenary wire sag position. The corresponding downrange translators at endpoint truss position 4 then adjusts the tension in these catenary wires.

Power to the alignment system is normally off. Before each shot is fired, the power is turned on and a status and control panel is monitored. Any translator movement initiated by the sensors, appears on the status and control panel as a lighted button. Therefore, when the power to the alignment system is turned on and all the translator lights

on the status and control panel are off, the wires and the beads are in the present positions.

LASER LIGHTED PHOTOGRAPHIC STATION

The facility contains one laser-lighted photographic station located in the uprange end of the instrumented section. This photographic station obtains four orthogonal photographs, yielding a complete 360-degree view of the projectile as it passes the station on its downrange trajectory. A sketch of the laser-lighted photographic station is shown in Figure 9. The laser is an Apollo Model 22HD double pulsed Q-switched ruby laser. In the single pulse mode the laser has an energy of four joules with a pulse width of approximately 20 nanoseconds (nsec). The pulse separation in the double pulse mode may be selected between 1 μsec and 500 μsec. The energy in each pulse may be chosen under the restriction that the sum of the energies cannot exceed four joules unless a pulse separation greater than 100 μsec is used (this permits significant repumping of the ruby rod). The total beam divergence is 6 milliradians at the half power points and the initial beam diameter is 1.59 centimeters.

The initial laser beam is split such that four beams of equal strength are passed into each of the four beam divergers. The beam divergers consist of 12.7-centimeter diameter Fresnel lenses which expand the beams to about 46 centimeters at the approximate range centerline. Located at about 45 degrees from the centerline of the diverged beams are four, high grade, first surface mirrors. A commercial view camera with a 30.5-centimeter focal length lens is positioned in front of each mirror and focused approximately to the range centerline.

The triggering system used for this station is an infrared emitter and detector identical to the ones used for the shadowgraph stations. Shot and camera identification information is strobed onto the film prior to loading the film cassettes into the individual cameras. The film used is 10.2 by 12.7-centimeter Kodak Linagraph Shellburst® film. Typical laser lighted photographs of models in free-flight are shown in Figures 10, 11, and 12.

X-RAY PHOTOGRAPHIC STATION

The x-ray station uses a Hewlett Packard Model 730-4/2350 flash x-ray system with four remote x-ray heads containing hard x-ray tubes. The remote heads and associated film holders can be configured into four inline stations or positioned orthogonally, on a light aluminum framework located within the blast chamber.

The high voltage power supply, nitrogen pressurized high voltage pulsers, remote trigger amplifiers, and nitrogen bottles are located in the hallway adjacent to the blast chamber. The projectile is detected by a light screen or similar trigger device mounted on the front of the

aluminum framework. The high voltage is set remotely from the main console in the control room. Appropriate trigger delays are dialed in at the delay trigger amplifiers. Coarse delays of 10 μsec, 100 μsec, 1 msec, 10 msec, and 100 msec can be switched in and a precision 10-turn heliopot adds in any delay between the coarse settings.

The film presently being used is Kodak RP-54® (RPX-OMAT) x-ray film in the 35.6 by 43.2 centimeters and 35.6 by 91 centimeters formats. The film holders also contain Radelin TI-2 intensifying screens. For quick x-ray inspection there are also four Hewlett Packard #43132 x-ray Polaroid Radiograph Cassettes which use Type 52® Polaroid film in the (10.2 by 12.7 centimeters) format. These cassettes also contain integral intensifying screens. Figure 13 shows typical x-ray penetration and operating characteristics of the system. Future plans call for use of soft x-rays to provide optimum film contrast for low density objects such as plastic and nylon.

FUTURE SYSTEMS PRESENTLY IN PLANNING

At present, one complete multispark station is installed within the facility and has been used to checkout and optimize the design concept. The purpose of such a photographic station is to provide a high density of position-orientation measurements over a short flight interval. This is required in order to define the angular motion of an object which has a very high nutational rate. Eventually, five complete multispark stations are to be installed. These stations will be very similar to the single spark stations presently installed with the exception of the four spark sources surrounding each camera and the size of the reflective screens. The reflective screens are 2.44 meters square and the triggering is accomplished using the same IR screens previously discussed. When the model penetrates the IR screen the first pair of orthogonal sparks is discharged consistant with the delay corresponding to the expected velocity; timing data will be obtained for only the first pair of spark charges. The remaining three pairs of sparks are discharged in sequence, also consistent with the expected velocity. A perspective sketch of a multispark station is shown if Figure 14.

The four spark sources are designed such that each illuminates only a 0.61-meter strip of the reflective screens. Therefore, four photographs are obtained on each sheet of film and none of the images are double exposed (See Figure 15). This system along with the 50 shadowgraph stations previously mentioned will produce a total of 70 position-attitude measurements as the model traverses the instrumented portion of the range. For a complete description of the multispark station see Reference 4.

A second system presently being installed is a data diagnostic system. This system which is a Holophotal Equipment Readiness Monitoring Network (HERMN), will provide a pretest and posttest evaluation of the status of

the range instrumentation. All of the holophotal instrumentation previously described provides crucial information for the free-flight data reduction process. The failure of any one or number of stations caused irrecoverable gaps in the data collection process. As already established, each station in the range uses photographic film as the data recording medium. This film is removed from the facility, processed at the ADTC/Parks Photographic Laboratory, and returned to the range. Until the film is returned to the range personnel, no diagnostic analysis of the information on the film can be made to identify holophotal equipment failures.

A typical shadowgraph station has several events which must occur before satisfactory pictures are obtained. Each event or binary coded data (BCD) point can be analyzed to produce some diagnostic information.

The major task involved with diagnosing problem areas is the acquisition and timely monitoring of the data. The solution to this problem is the implementation of the HERMN. The overall system is identified in block diagram form in Figure 16. The largest portion involves modification to the existing holophotal stations to provide party line type inputs to the tunnel data acquisition unit. The interface system consisting of data interface modules (DIM) and the tunnel data acquisition control (TDAC) provides for interrogation and monitoring of each station before, during, and after a test is conducted. Each DIM is a micro-processor capable of running short interrogation programs on the station equipment. The information from the DIMs is stored in the TDAC which is normally under control of a HP 2100A minicomputer. The computer may ask for all or part of the data collected. The automatic data processing equipment (ADPE) consisting of the minicomputer with 32K of resident core, a five megabyte magnetic disc, and typical associated peripherals, provides immediate and permanent storage for the data collected from the TDAC.

Following the input of all required data, a resident software program will perform a logical analysis and produce a diagnostic print out. The test engineer can then decide which station or stations require attention before the next shot. The test engineer will also use the information produced to insure all stations are secure (i.e., shutter closed before the main tunnel lights are turned on).

The TDAC will also provide a preliminary velocity profile by collecting each pulse from the infrared detector screens and identifying each event with a time of occurrence. The times for each pulse are sent to the computer where a resident program has been loaded with the distance between the detector screens. From the times and distances, the velocities of the tested model are computed.

A graphic terminal is used as a part of the peripheral equipment. This Tektronic produced storage scope provides normal terminal keyboard functions and a means of producing graphical plots of the data. A thermal hard copy unit works with the terminal to provide on command perma-

nent copies of the graphs. Graphs can also be produced by a digital plotter. Permanent storage is provided by using a nine track digital magnetic tape unit, punched paper tape, line printer, or retained on 2.5-megabyte disc cartridges used in the ADPE disc unit.

A third system presently in the early stages of development is a holographic station. The need to observe the surface and/or the flow field characteristics of a test model indicates that a three dimensional means of acquisition is required. Initial experiments are presently being performed on a type of 360-degree holographic station. Most of the work has been of a static nature in order to build a data base for the dynamic work. However, no conclusive dynamic results have been attained at this time.

SECTION V

DATA REDUCTION

FILM READING

The shadowgrams obtained during a test program are read and numerically coded by personnel of the Computer Sciences Laboratory. The machines presently used are manually operated optical film readers, as shown in Figure 17. These machines are scaled to approximately 138 counts per centimeter which, when used with a magnification factor of five, produces an equivalent 690 counts per centimeter. Once the film has been sorted and mounted on the machine, the readings of the points of interest on the film are numerically coded and automatically punched on data processing tapes. Alternate film reading machines more optimumly designed for reading of the shadowgrams obtained from the facility are presently being investigated.

The points of interest on each shadowgram are: the lower left reference bead (See Figure 5), the lower right reference bead, the upper right reference bead, and the point or points on the shadow of the model to be read. The lower right reference bead represents the origin of the film axis system and the range coordinates of this bead are precisely known. The lower left bead is read to determine a scale factor (in the horizontal direction) relating the film measurements to range distances. This bead also defines the horizontal film axis; whereas, the vertical film axis is defined as perpendicular at the origin to the line connecting the two lower beads. The upper right reference bead is read only to determine a scale factor for the vertical direction. The position of the shadow of the model is then determined relative to this defined coordinate system and transformed into range coordinates.

SPATIAL POSITIONS AND ORIENTATION

Once the range coordinates of both orthogonal shadows of a point on the model in space have been determined from the shadowgram, the range coordinates of this point on the model are computed by finding the closest approach of two vectors. These two vectors are defined by rays connecting the predetermined spark gap coordinates to the measured shadow coordinates. Therefore, the point in space corresponds ideally to the intersection of the two vectors. Since some measurement error is expected in both the shadow measurements and the spark gap locations, the two vectors will not exactly intersect. The unknown point is therefore assumed to lie halfway along the shortest line connecting the two vectors.

When determining the spatial position and orientation of a model in free-flight, the positions of concern are those defining the center of mass of the model and the orientation defined by the direction cosines of the principal axis of the model and with respect to the range axis system. In order to determine the direction cosines of the principal axis, the coordinates of two points lying on the principal axis are determined. The two points are generally the nose of the model and the center of the base. The vector defined by the two points and coinciding with the principal axis uniquely establishes the direction cosines. The coordinates of the center-of-mass are computed by using the known distance between the nose of the model and the center of mass (measured prior to launching) and recognizing that the center of mass lies on the principal axis.

COEFFICIENT EXTRACTION

Aerodynamic coefficients are extracted from the model's measured time, position, and attitude histories by using linear theory data reduction techniques of References 5 and 6, and the nonlinear numerical integration technique of Chapman and Kirk (Reference 7). These techniques are incorporated into two independent data reduction digital computer programs.

One of these computer programs is used for analyzing free-flight motion of more conventional types of models (objects having at least three planes of symmetry) tested in ballistic ranges. This program is discussed in detail in Reference 8. The program initially accomplishes a linear analysis of the rolling, yawing, and swerving motion of the model and uses the linear solutions as initial values for the nonlinear numerical integration technique. Options to the program permit the user to do only the linear data reduction, if desired, or to do both linear and nonlinear reductions. After individual data sets have been reduced both linearly and nonlinearly, the program has the capability of determining a common set of aerodynamic characteristics that best fit the measured position and orientation histories of up to three separate shots.

The second computer program is used for analyzing the motion obtained from asymmetric bodies (objects having only one plane of symmetry) such as aircraft configurations and some missile configurations. This program parallels the procedures used in the conventional data reduction program. The equations of motion used were obtained from Reference 9. For a complete description of this program refer to Reference 10.

Both programs are run on a CDC 6600 computer and the execution of the programs is controlled from a remote terminal located at the facility (See Figure 18). Other more advanced techniques of reducing free-flight position-attitude-time measurements are presently being investigated. Two of the advanced techniques are the Maximum Likelihood Method and the Extended Kalman Filter and will be included in the data reduction schemes if they prove to be advantageous over the present methods.

PRECISION OF MEASUREMENTS

It should be recognized that the precision to which the spatial position and/or orientation of a model can be determined is related to the geometry of the model. For example, the range coordinates of a model's nose can be more precisely determined if the model has a sharp, well defined nose tip. Also, the orientation of a long model can be obtained more precisely than that of a short model because the two points on the principal axis which define the orientation are further apart and therefore any measurement errors associated with the two points have a smaller effect. This indicates that the spatial positions and orientations of a long pointed configuration are better determined than that for a short blunted configuration. Unfortunately, some projectiles fall into the latter category; however, most missiles and rockets are consistent with the first category.

The present measuring capability of the facility is approximately 0.08 degree and 0.03 centimeter respectively for the orientation and position of well defined points in space. These listed values of the present measuring capability are not considered to be the best that can be obtained from the facility. Because the facility is relatively new, some possible error sources have not as yet been defined and calibrated out of the system. For example, lens distortion effects, which are known to exist, have not been systematically determined and accounted for in the raw film readings. This effort is presently in progress and will be accomplished in the near future. Optimization of the film reading process is another area where dividends in obtaining precise measurements might be realized. The process of improving and maintaining the measurement precision of this test facility will be a continuing effort.

SAMPLE AERODYNAMIC DATA

A few typical aerodynamic coefficients and derivatives are shown in Figures 19 and 20. These figures are presented in order to indicate the type of data that can be obtained from the Aeroballistic Research Facility. However, it should be obvious that these are not the only coefficients and derivatives that can be obtained. In fact, all force and moment data, including their nonlinearities, can be determined from the measured free-flight motion patterns if these coefficients and derivatives have a measurable effect on the observed motion and if these effects can be modeled in the reduction routines. Also, when testing full scale configurations (which is frequently the case), such added benefits as flow observation, precise roll histories, and actual dispersion measurements can be invaluable to the analyst and test engineer.

SECTION VI

CONCLUDING REMARKS

Much of the instrumentation and techniques used in establishing the Aeroballistic Research Facility have been significantly altered since the conceptual stage several years ago (See Reference 11). For example, the automatic range calibration technique as discussed in Reference 12 and mentioned in References 4 and 11 has proven inadequate. Alternate means of calibrating the range (determining the range coordinates of the spark gaps and reference beads) have been developed and are presently used. These techniques are considered an improvement over the conventional techniques previously used and will be the subject of a forthcoming paper. Other changes have also been incorporated into the alignment system, spark gap design, and chronographs.

Frequently, when changes or alterations have been made, they have impacted the logic behind some other aspect of the facility. For example, when using the automatic range calibration technique it was advantageous to have the spark gap assembly mounted to the camera housing. However, since the automatic range calibration procedure has been discarded it would be more efficient from a maintenance viewpoint to separate the camera and the spark gap assembly; in fact, plans are progressing to accomplish this. Also, even before the facility became operational it was apparent that some desirable features were lacking and the design and installation of systems such as the multispark shadowgraph stations and the HERMN among others were initiated.

The facility has only been operational as of March 1976. It is expected that innovative systems and techniques will be continually tried and incorporated into the facility.

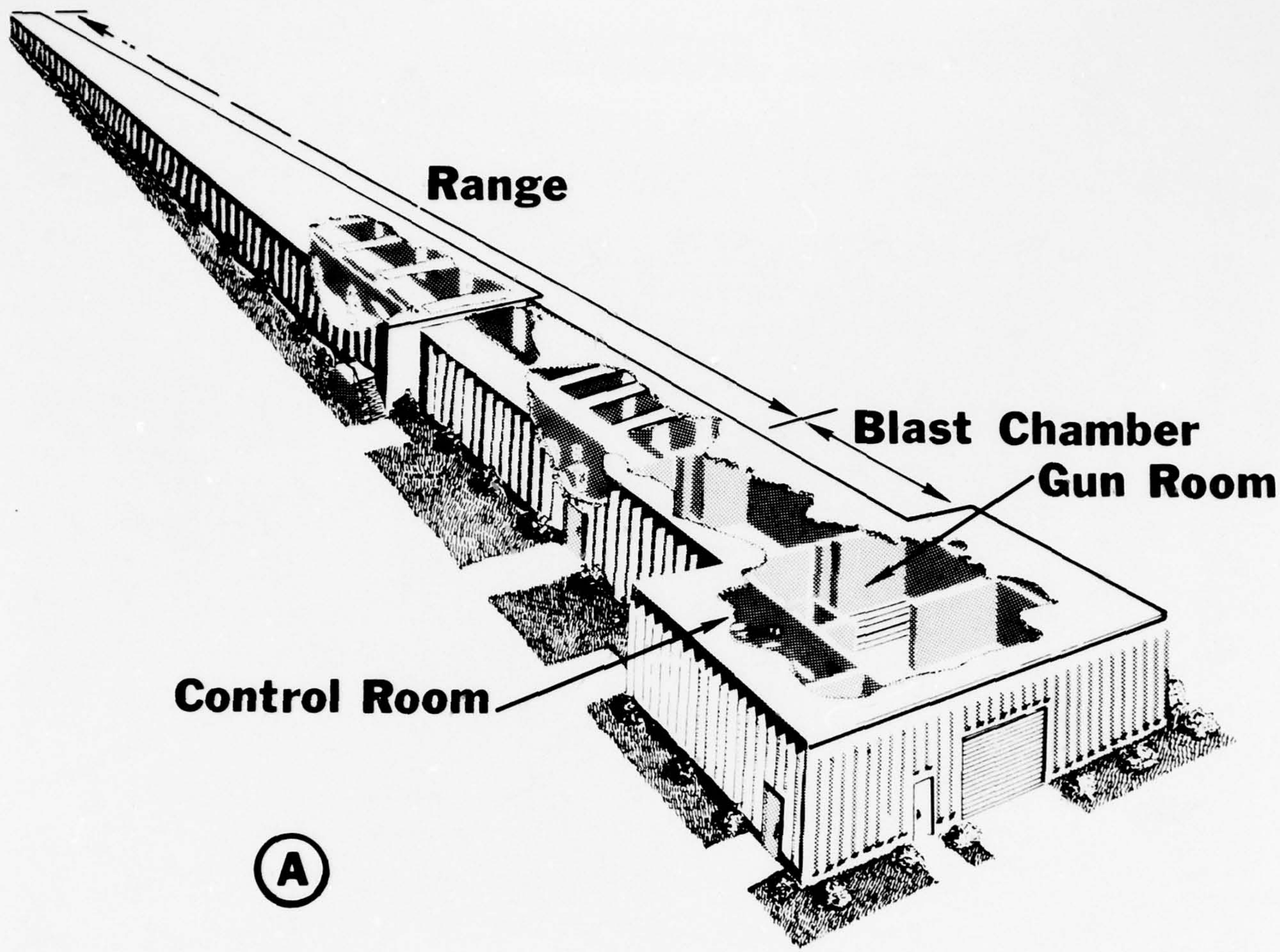


Figure 1. Aeroballistic Research Facility

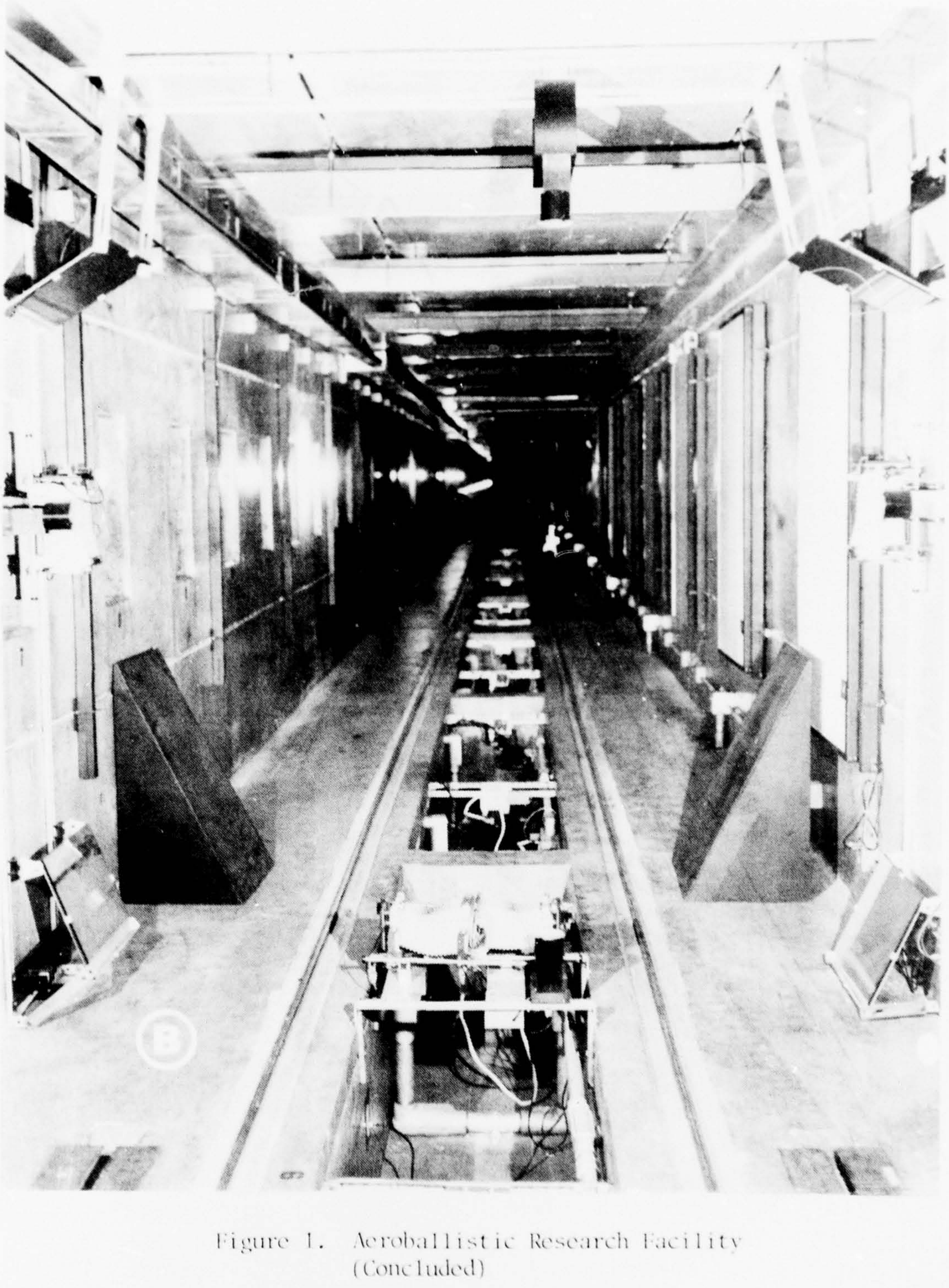


Figure 1. Aeroballistic Research Facility
(Concluded)

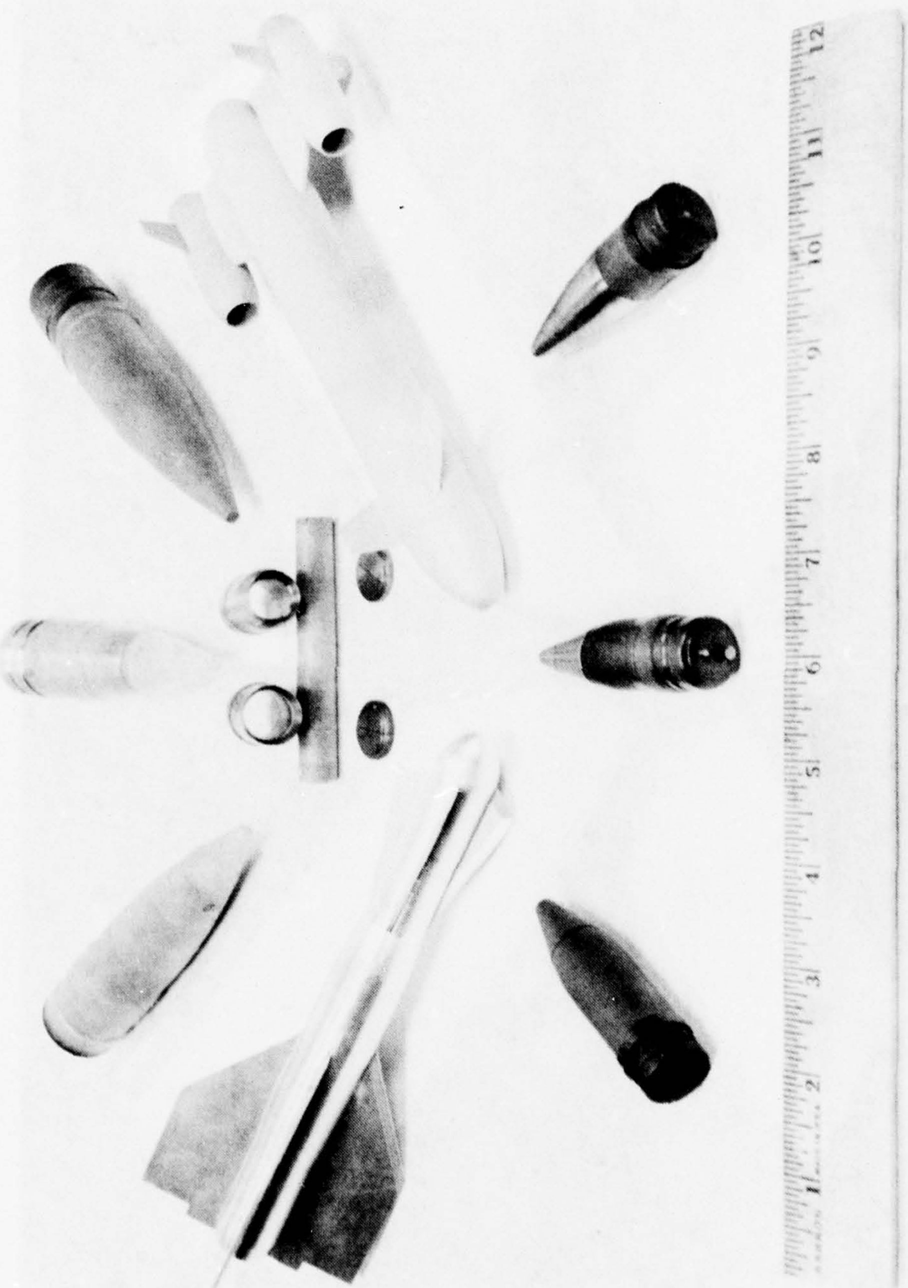


Figure 2. Typical Models and Projectiles

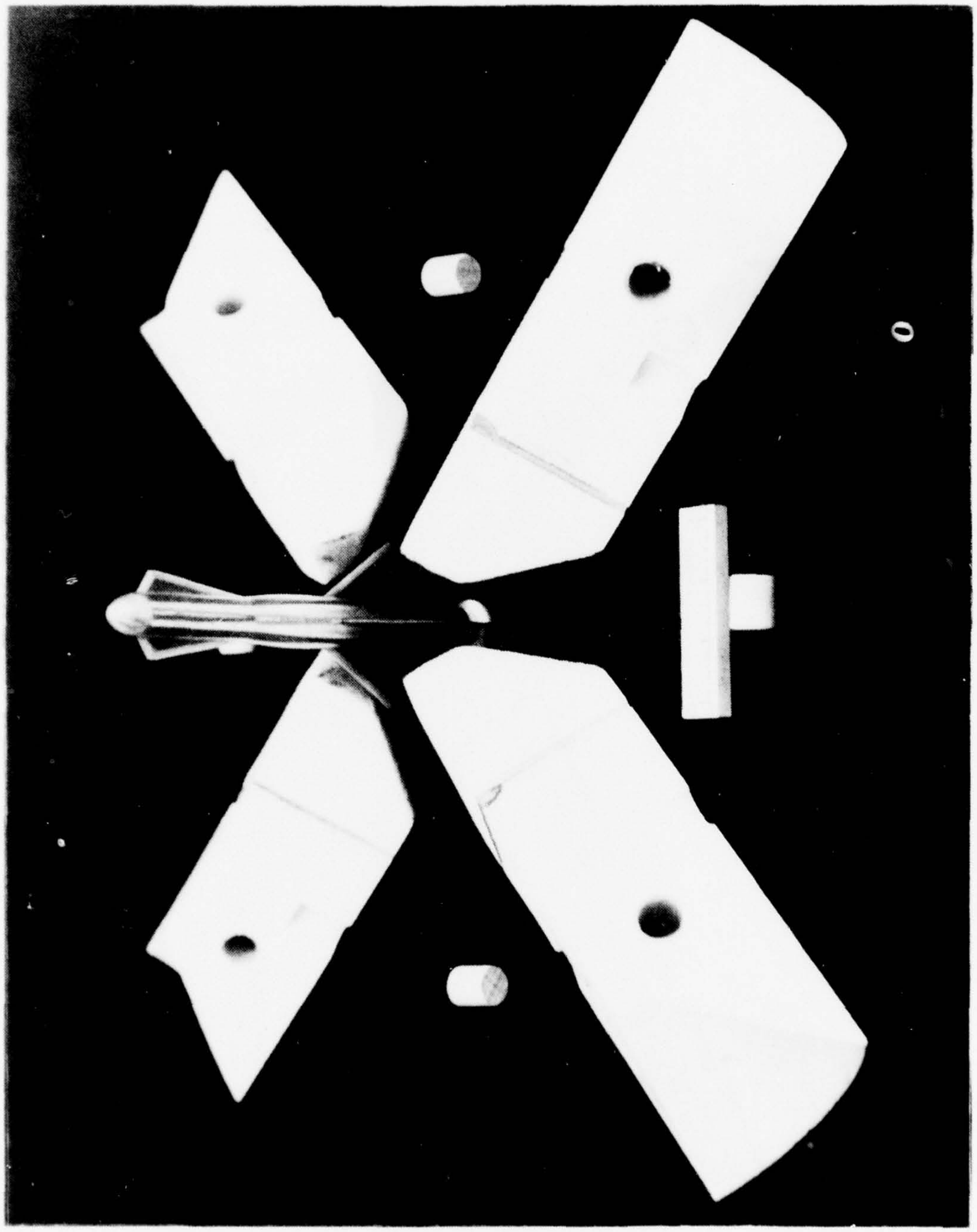


Figure 3. Typical Model-Sabot Package

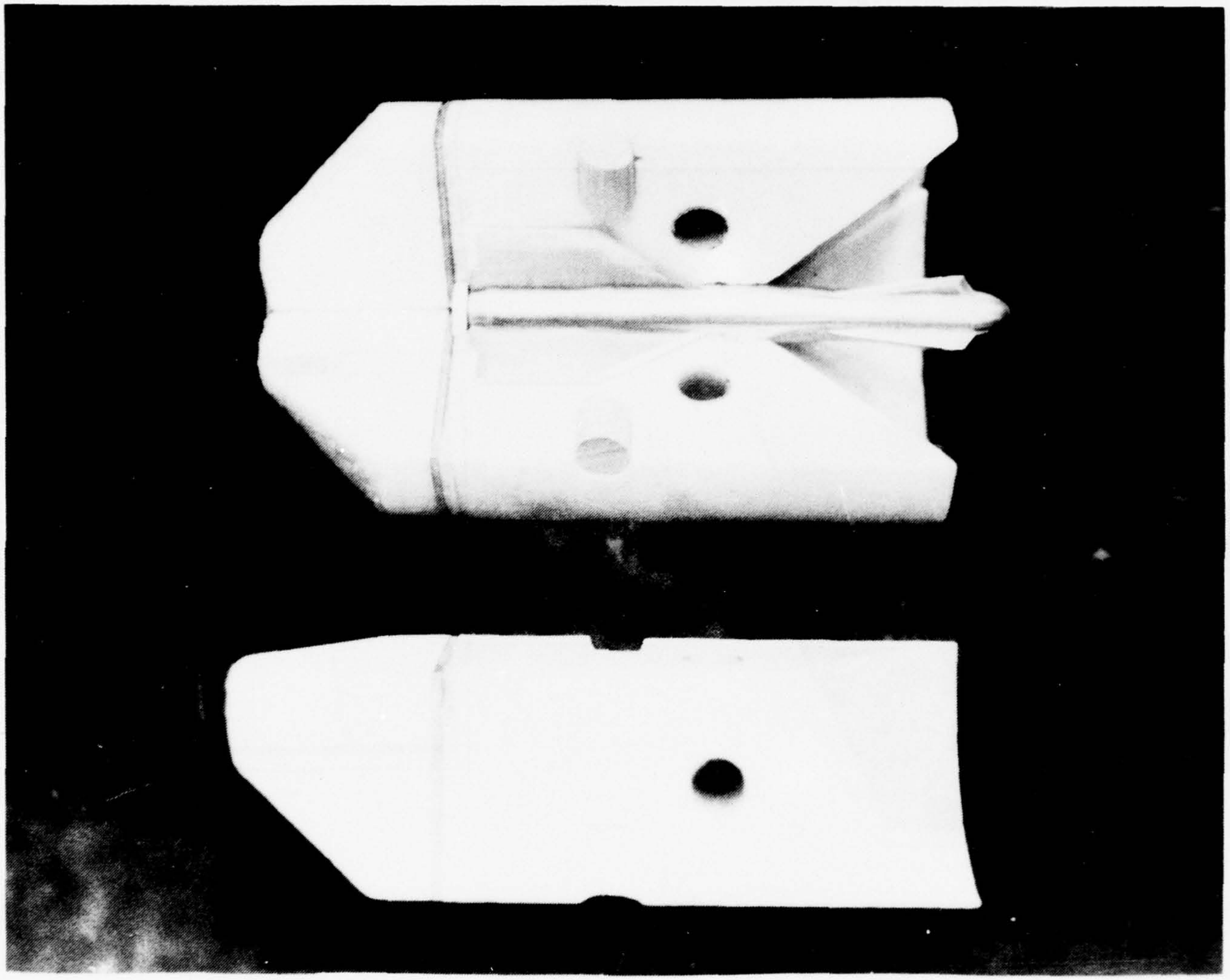


Figure 3. Typical Model-Sabot Package (Concluded)

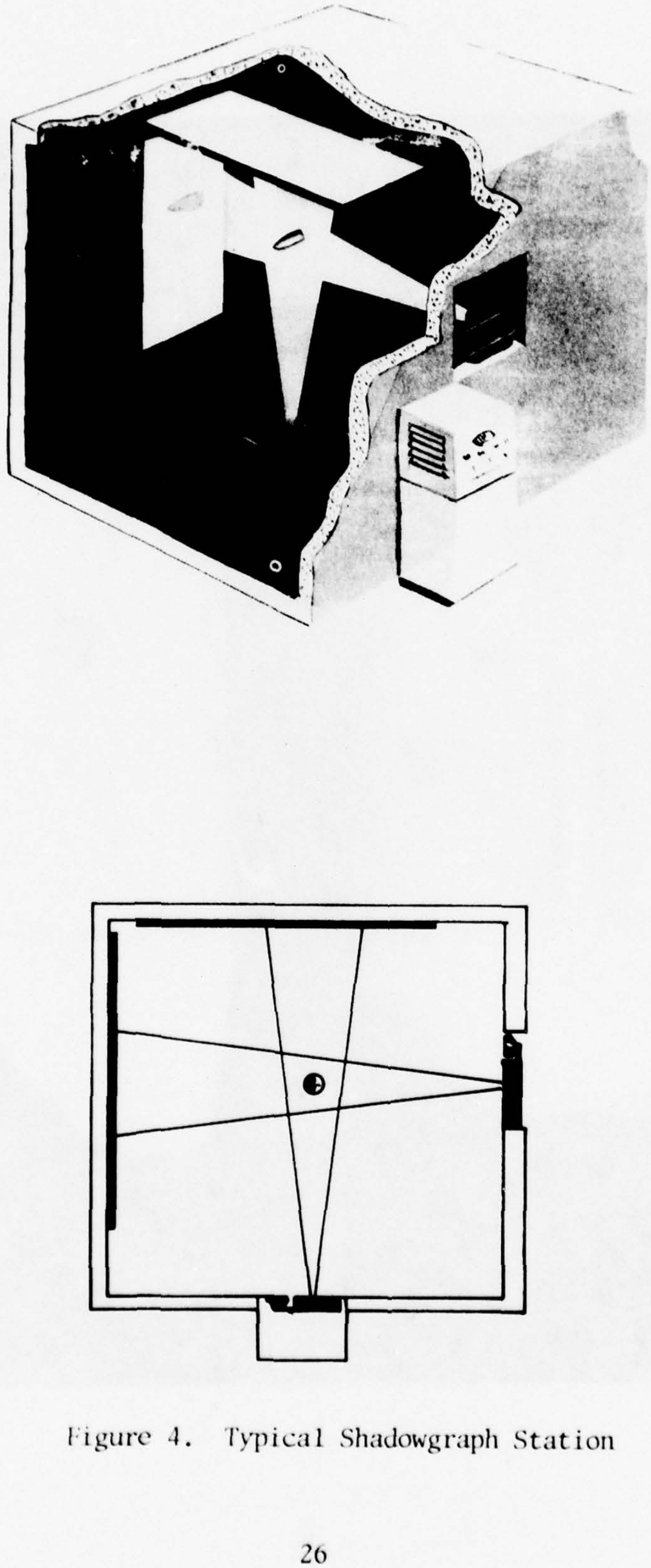


Figure 4. Typical Shadowgraph Station

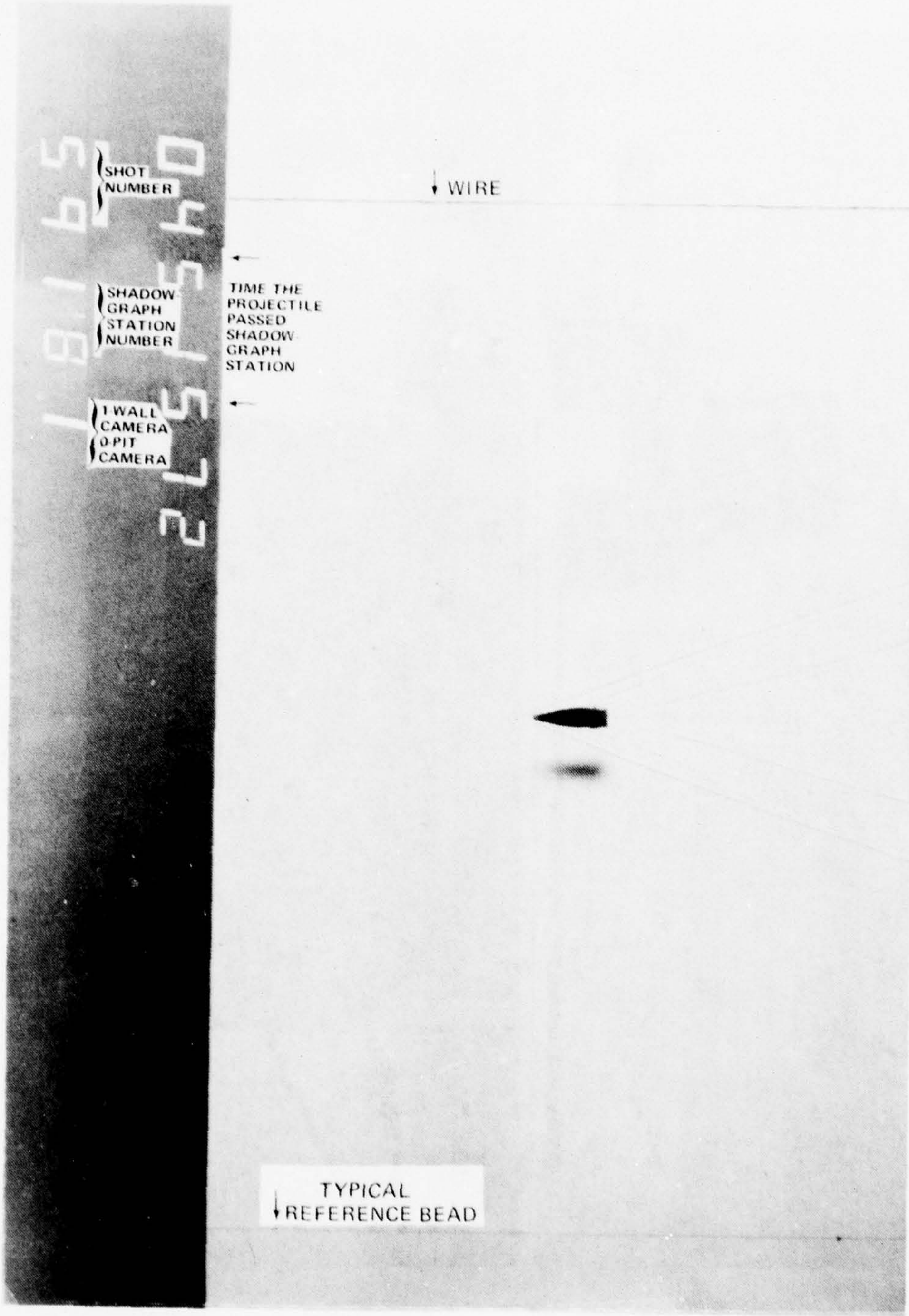


Figure 5. Typical Shadowgram

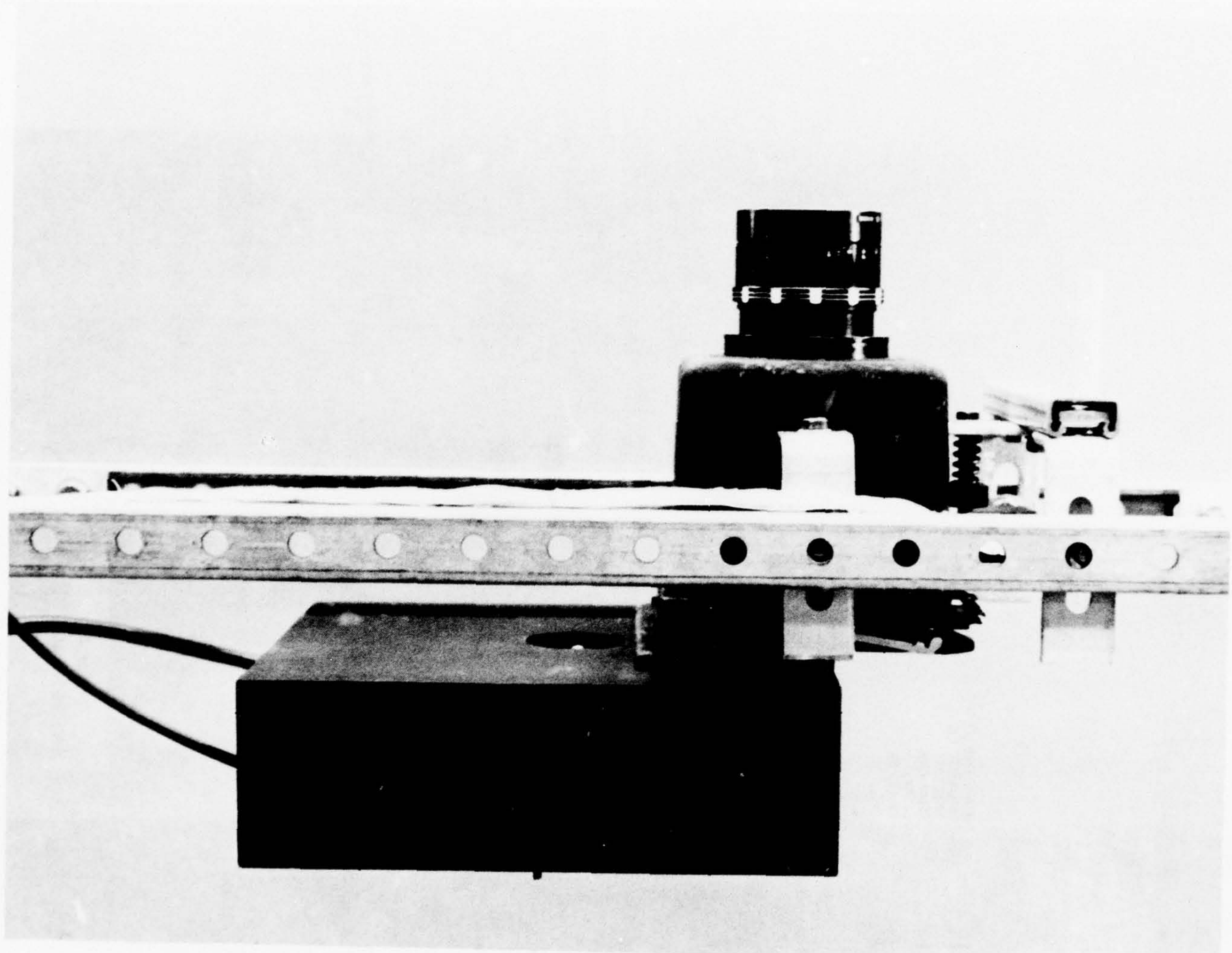


Figure 6. Shadowgraph Camera and Spark Assembly

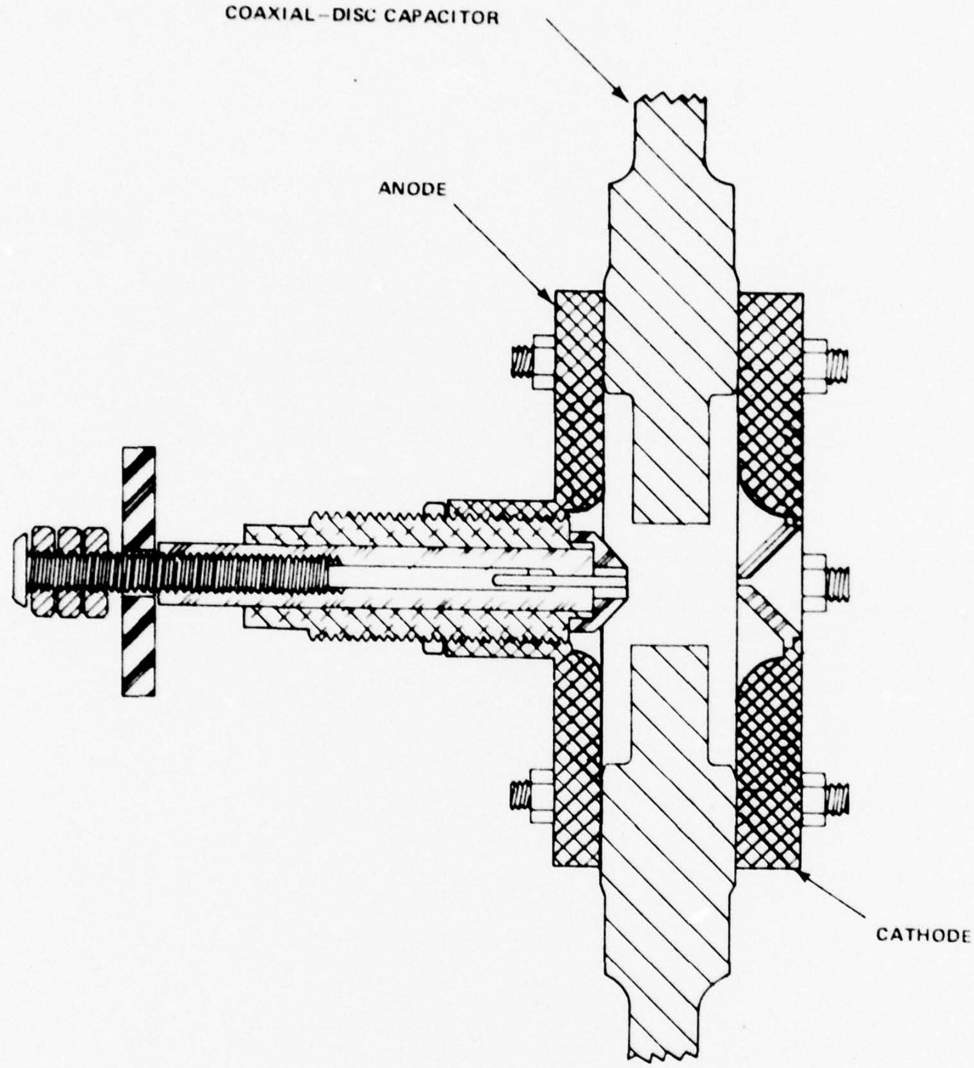
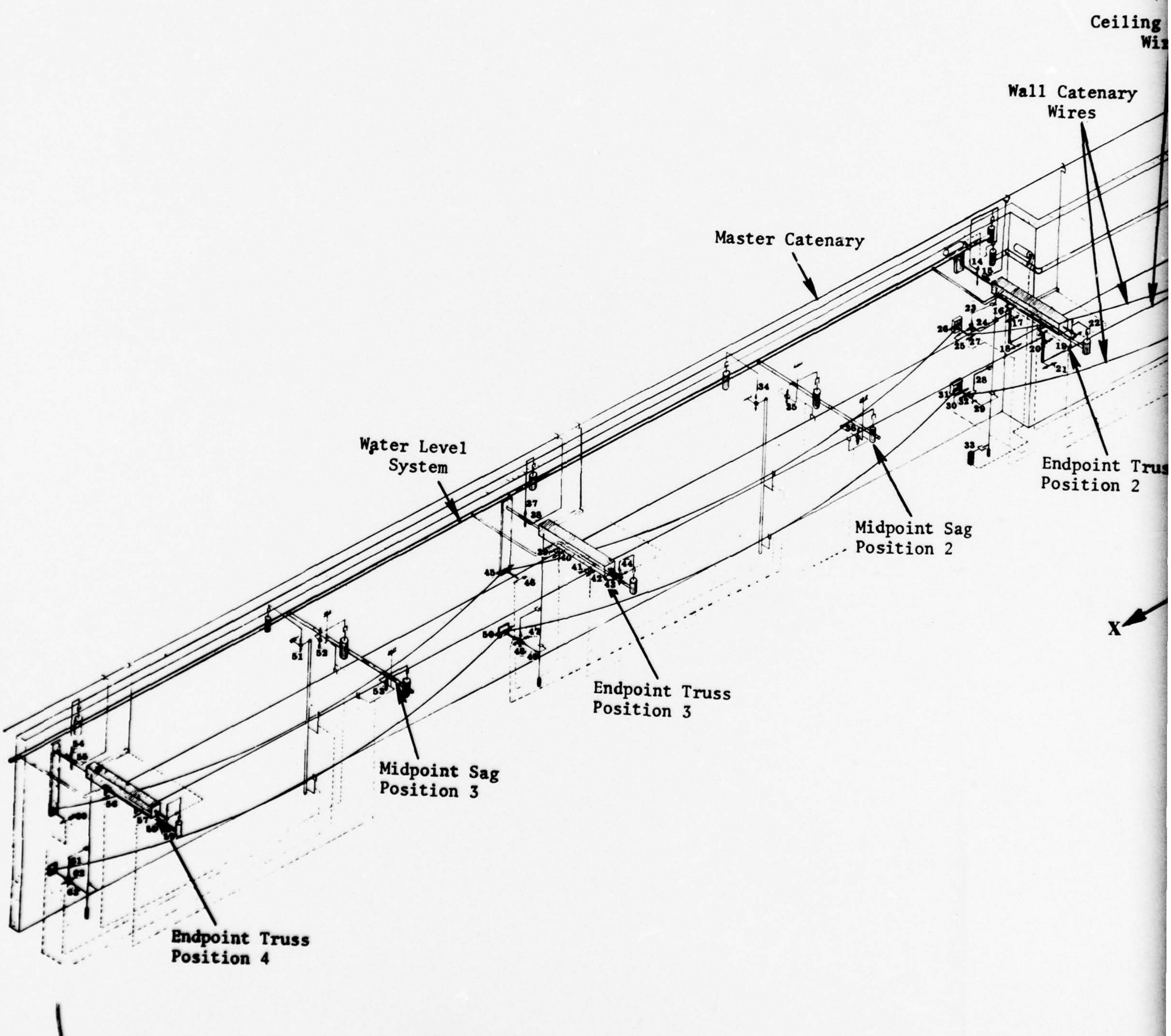


Figure 7. Cross Section of Spark Gap

(The reverse of this page is blank)



Ceiling
Wi
Wall Catenary
Wires
Master Catenary
Water Level
System
Midpoint Sag
Position 2
Endpoint Trus
Position 2
Endpoint Truss
Position 3
Midpoint Sag
Position 3
Endpoint Truss
Position 4
X

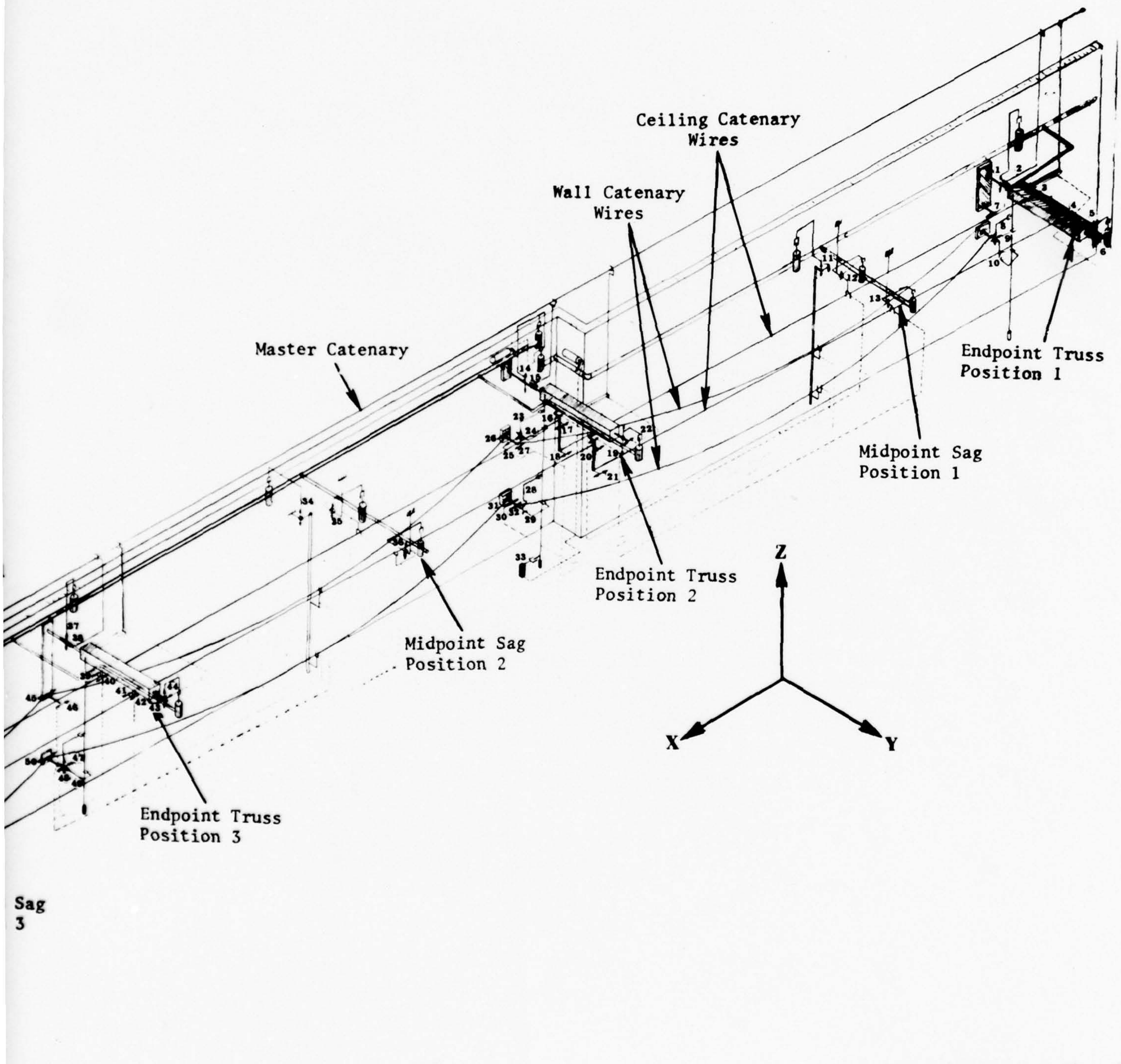


Figure 8. Alignment System Sketch

Legend for Figure 8

Endpoint Truss Position 1

1. Z movement of overhead truss and top wall catenary; senses fluid level.

2. Y movement of overhead truss and interconnecting top wall catenary senses master catenary.

3. X movement; endpoint adjusting translator.

4. X movement; endpoint adjusting translator.

5. Z movement of far end of overhead truss. Senses water level to maintain level of overhead wires.

6. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

7. X movement; endpoint adjusting translator.

8. Z movement of endpoint of lower wall catenary; senses marker on plumb line from truss.

9. X movement of endpoint of lower wall catenary. Senses plumb line from overhead truss.

10. Y movement of endpoint of lower catenary. Senses plumb line from overhead truss.

Midpoint Sag Position 1

11. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

12. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 2.

13. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag.

Endpoint Truss Position 2

14. Z movement of overhead truss. In addition, this device serves as a means of maintaining the water level in link two of the level system.

15. Y movement of overhead truss; senses master catenary.

16. X movement of catenary interfaced to midpoint sag sensor. Moves both span 1 and 2 wires.

Legend for Figure 8 (Continued)

19. X movement of catenary, interfaced to midpoint sag sensor. Moves both span 1 and 2 wires.

22. X movement of far end of overhead truss. Maintains truss perpendicular to plane of master catenary. Senses master catenary.

23. Z movement of upper wall catenary. Senses marker on plumb line from over head truss.

24. Y movement of upper wall catenary. Senses plumb line hung from overhead truss.

25. X movement of upper wall catenary. Senses midpoint of span 1 catenary and moves accordingly. Moves span 1 and 2 wires.

28. Z movement of lower wall catenary. Senses marker on plumb line from overhead truss.

29. Y movement of lower wall catenary. Senses plumb line hung from overhead truss.

30. X movement of lower wall catenary. Senses midpoint of span 1 and moves accordingly. Moves span 1 and 2 wires.

33. Sensor reference for maintaining water level a constant distance from this point while the second pump system maintains a level height difference of 30.48 cm ± 0.0025 cm for the other link.

Midpoint Sag Position

34. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

35. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 3.

36. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag.

Endpoint Truss Position 3

37. Z movement of overhead truss and top wall catenary. Senses fluid level.

38. Y movement of overhead truss and interconnecting top wall catenary. Senses master catenary.

40. X movement of overhead catenary, interfaced to midpoint sensor for midpoint sag position 2.

42. X movement of overhead catenary, interfaced to midpoint sensor for midpoint sag position 2.

Legend for Figure 8 (Concluded)

43. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

44. Z movement of far end of overhead truss. Senses waster level to maintain preset level of overhead wires.

46. X movement of upper wall wires. Senses midpoint of span 2.

47. X movement of lower wall wires. Senses midpoint of span 2.

48. Z movement of lower wall catenary. Senses marker on plumb line hung from overhead truss.

49. Y movement of lower wall catenary, senses plumb line hung from overhead truss.

Midpoint Sag Position 3

51. Z movement of wall Invar® bar. Senses water level. Holds and positions sensors for midpoint sag measurement.

52. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 4.

53. Z movement of arm sensing water level and interconnected sensor to maintain a constant sag. Moves endpoint at endpoint truss position 4.

Endpoint Truss Position 4

54. Z movement of overhead truss and top wall catenary. Senses fluid level.

55. Y movement of overhead truss and interconnecting top wall catenary. Senses master catenary.

56. X movement of overhead catenary, interfaced to midpoint sensor for span 3.

57. X movement of overhead catenary, interfaced to midpoint sensor for span 3.

58. X movement of far end of overhead truss. Senses master catenary to maintain truss perpendicular to plane of master catenary.

59. Z movement of far end of overhead truss. Senses water level to maintain preset level of overhead wires.

60. X movement of upper wall catenary. Senses midpoint of span 3.

61. Z movement of lower wall catenary. Senses marker on plumb line hung from overhead truss.

62. X movement of lower wall catenary. Senses midpoint of span 3.

63. Y movement of lower wall catenary. Senses plumb line hung from overhead truss.

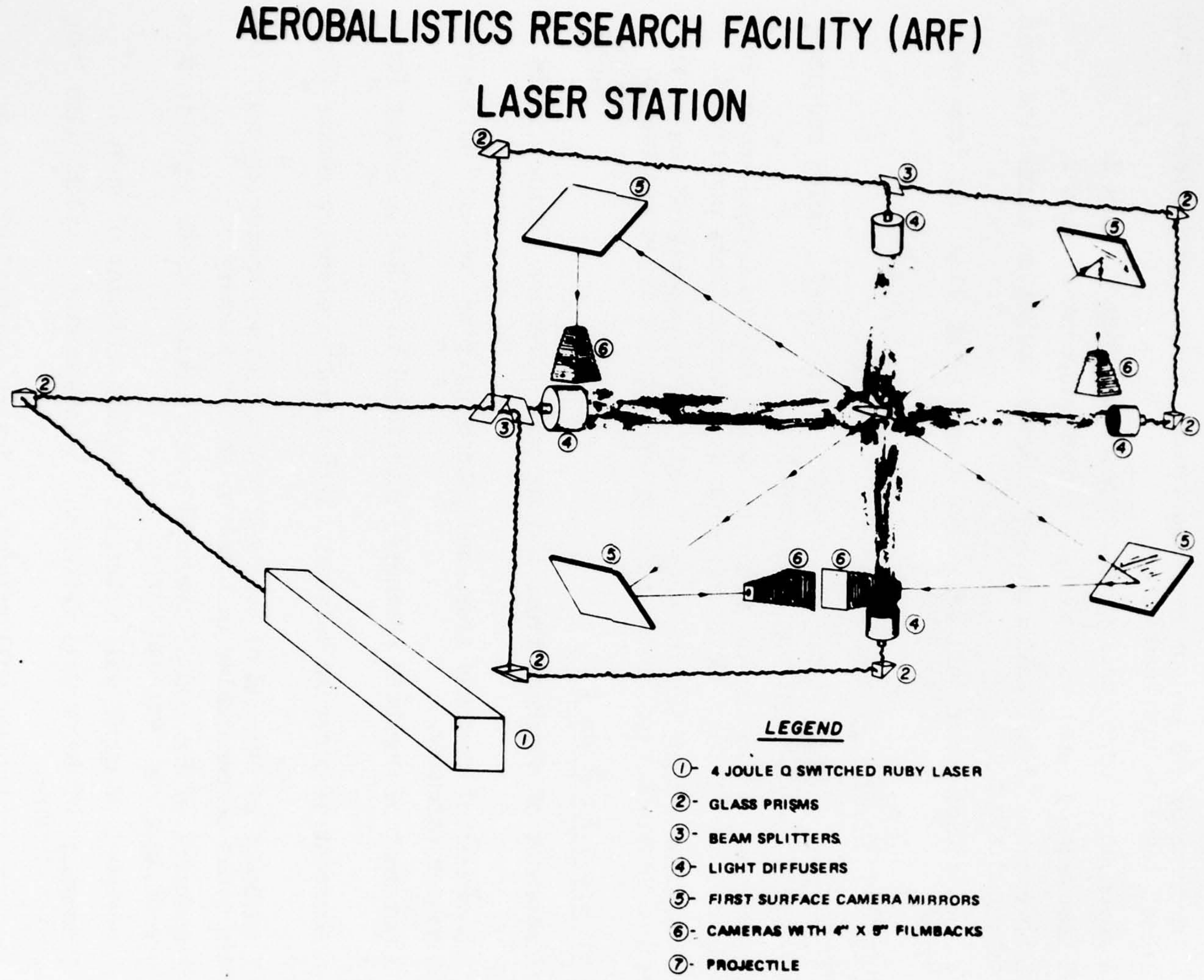


Figure 9. Sketch of Laser-Lighted Photographic Station

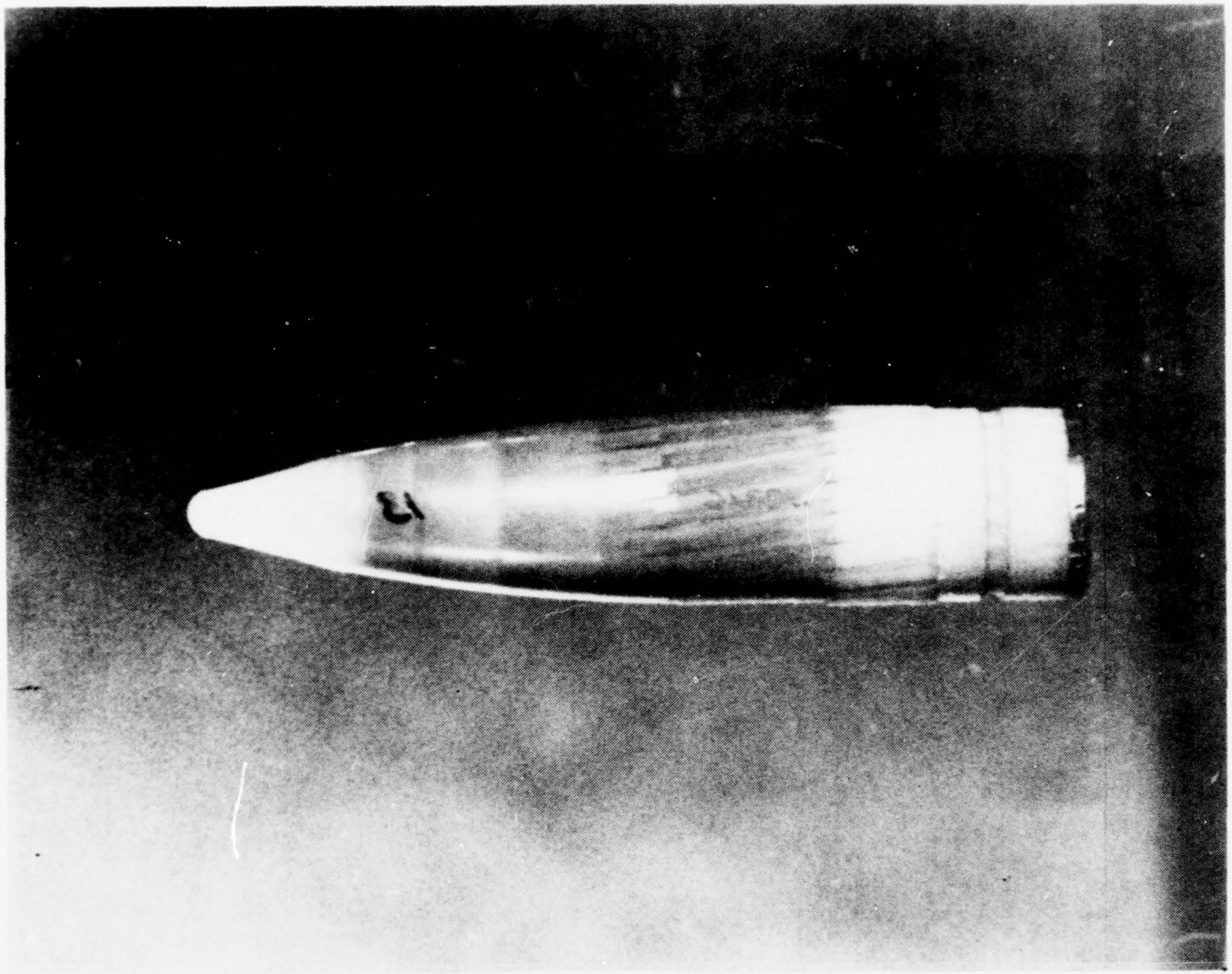


Figure 10. Typical Laser Lighted Photographs (30 mm Projectile)

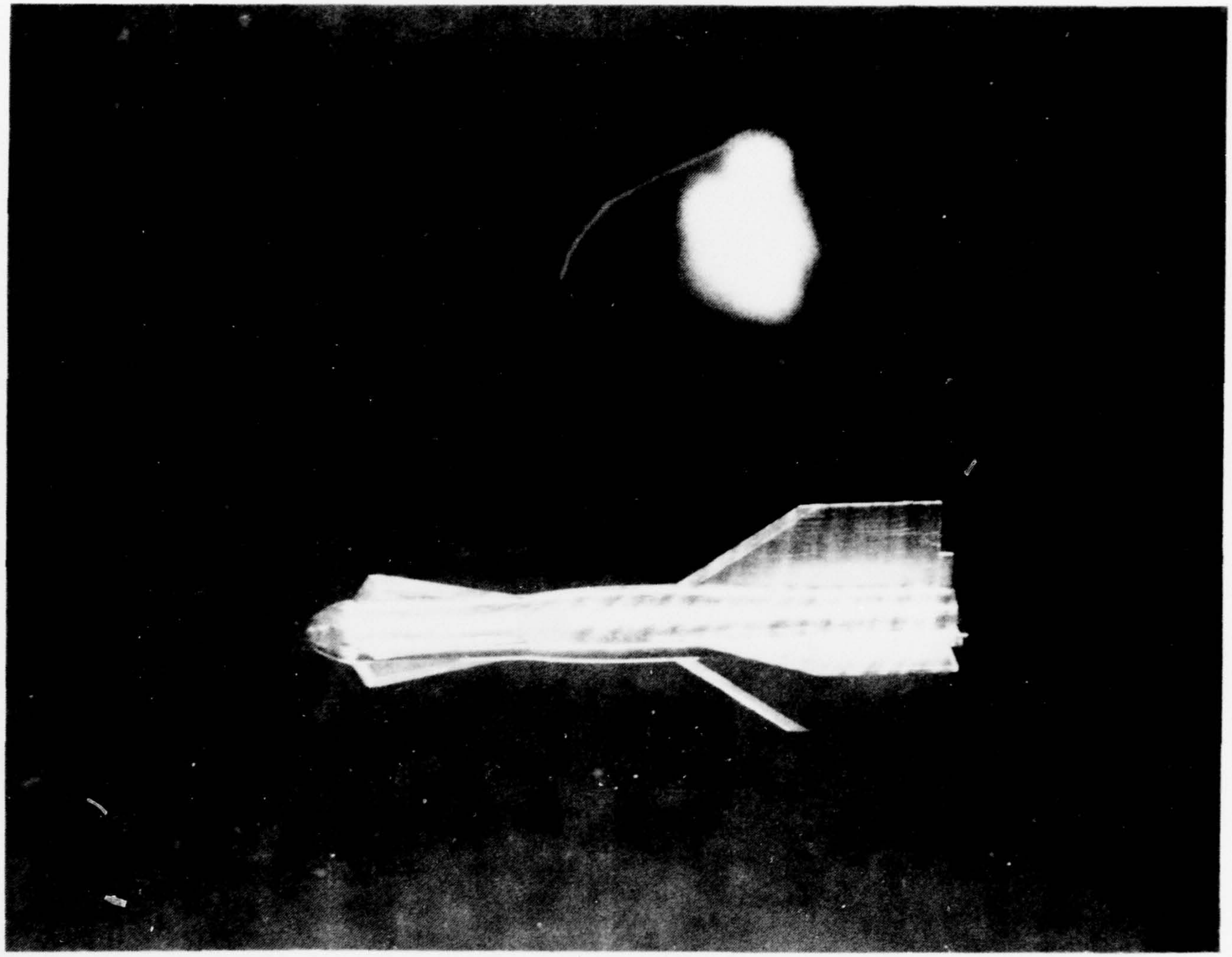


Figure 11. Typical Laser Lighted Photographs (Missile Configuration)

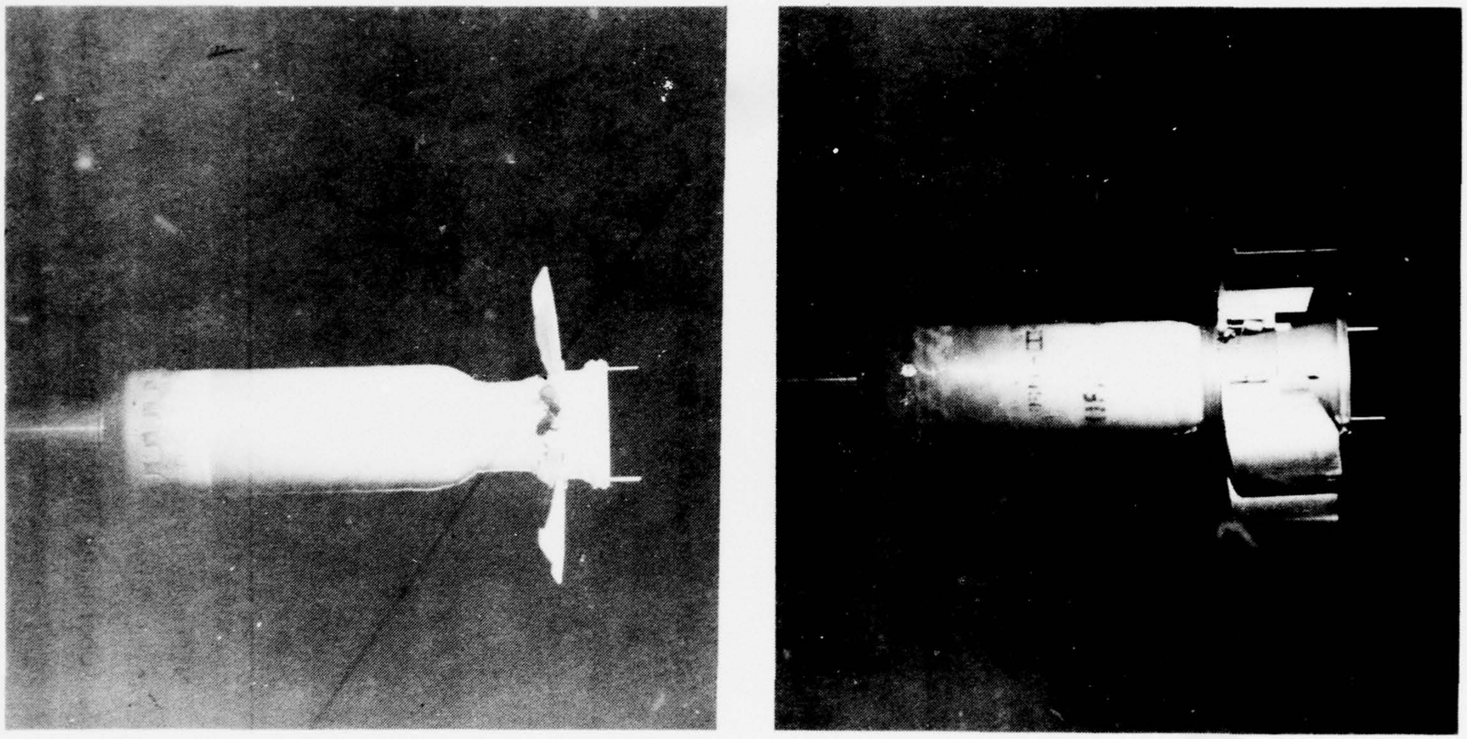
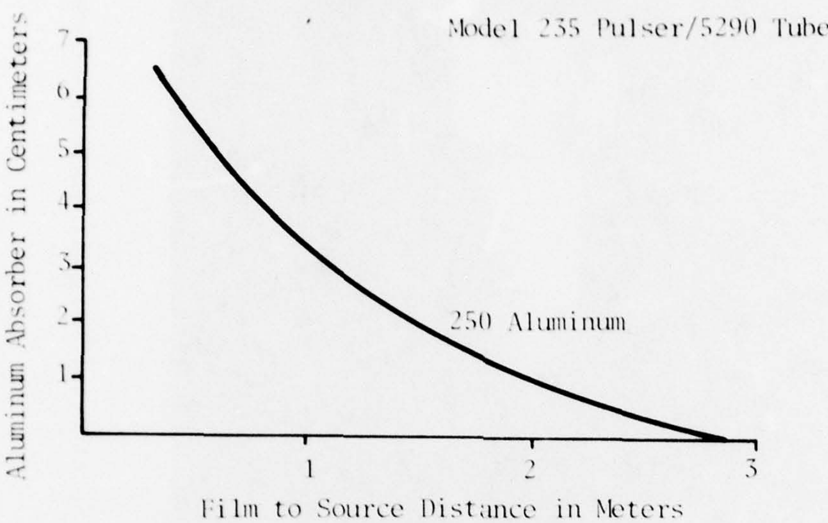
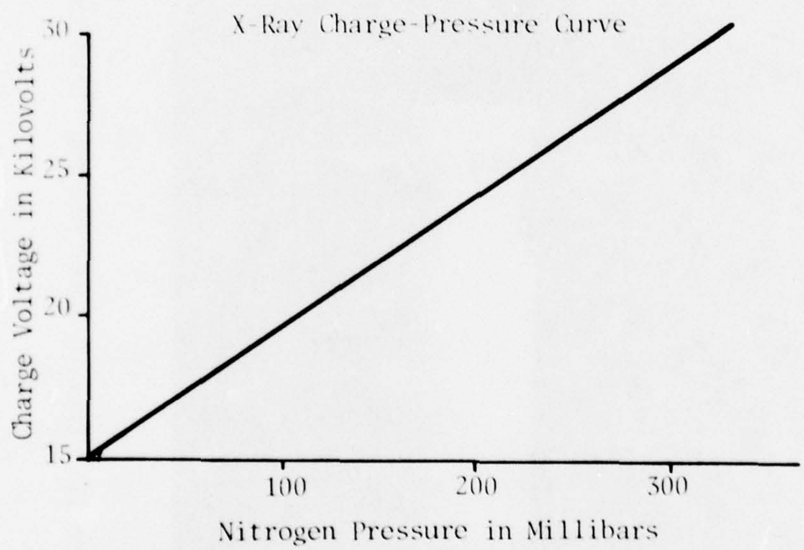


Figure 12. Typical Laser Lighted Photographs (Fin Sections of Two Full Scale Missiles)



A. Penetration Characteristics



B. Operating Curve

Figure 13. Operating Characteristics of the X-Ray System

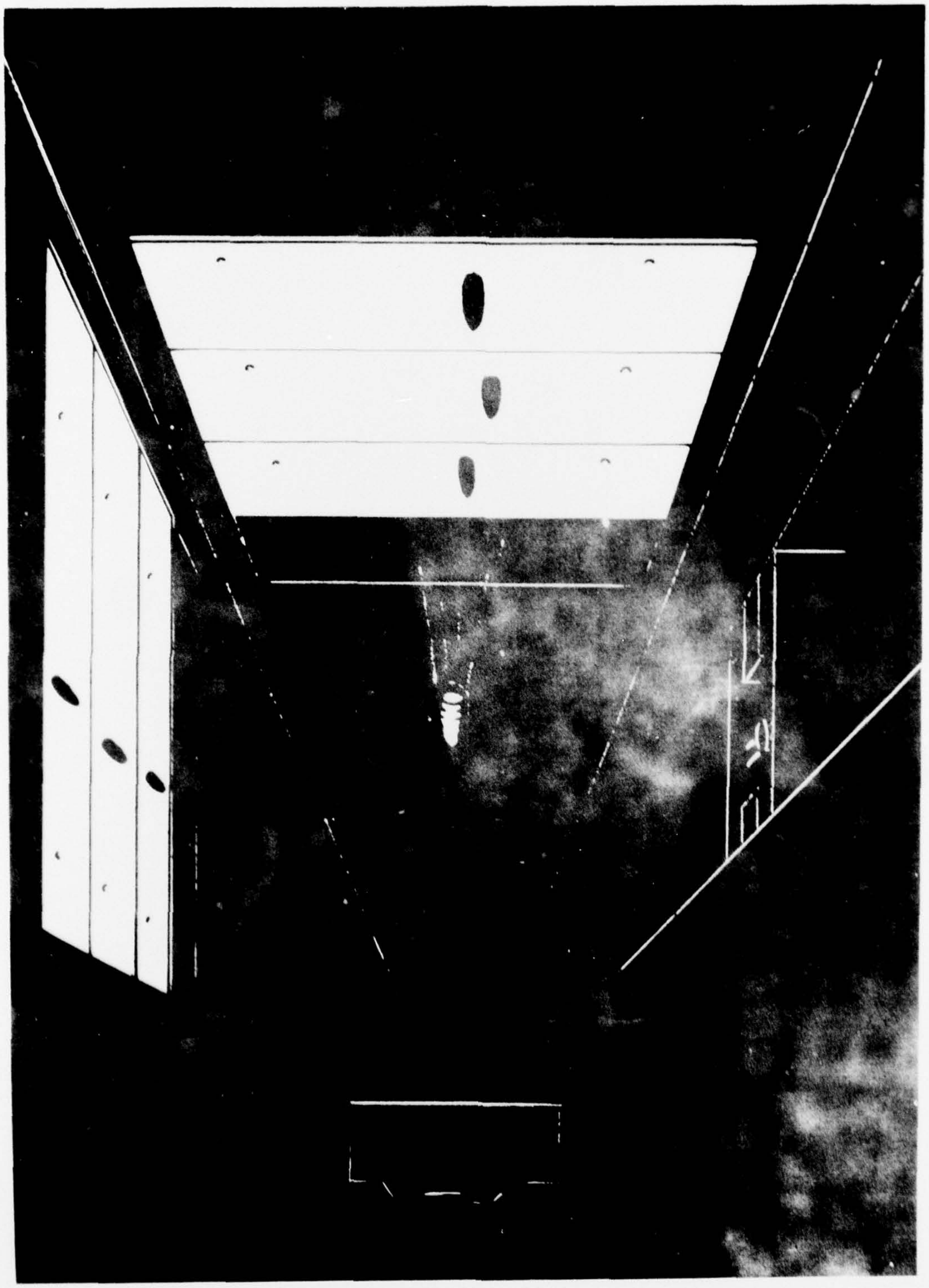


Figure 14. Perspective Sketch of a Multispark Shadowgraph Station

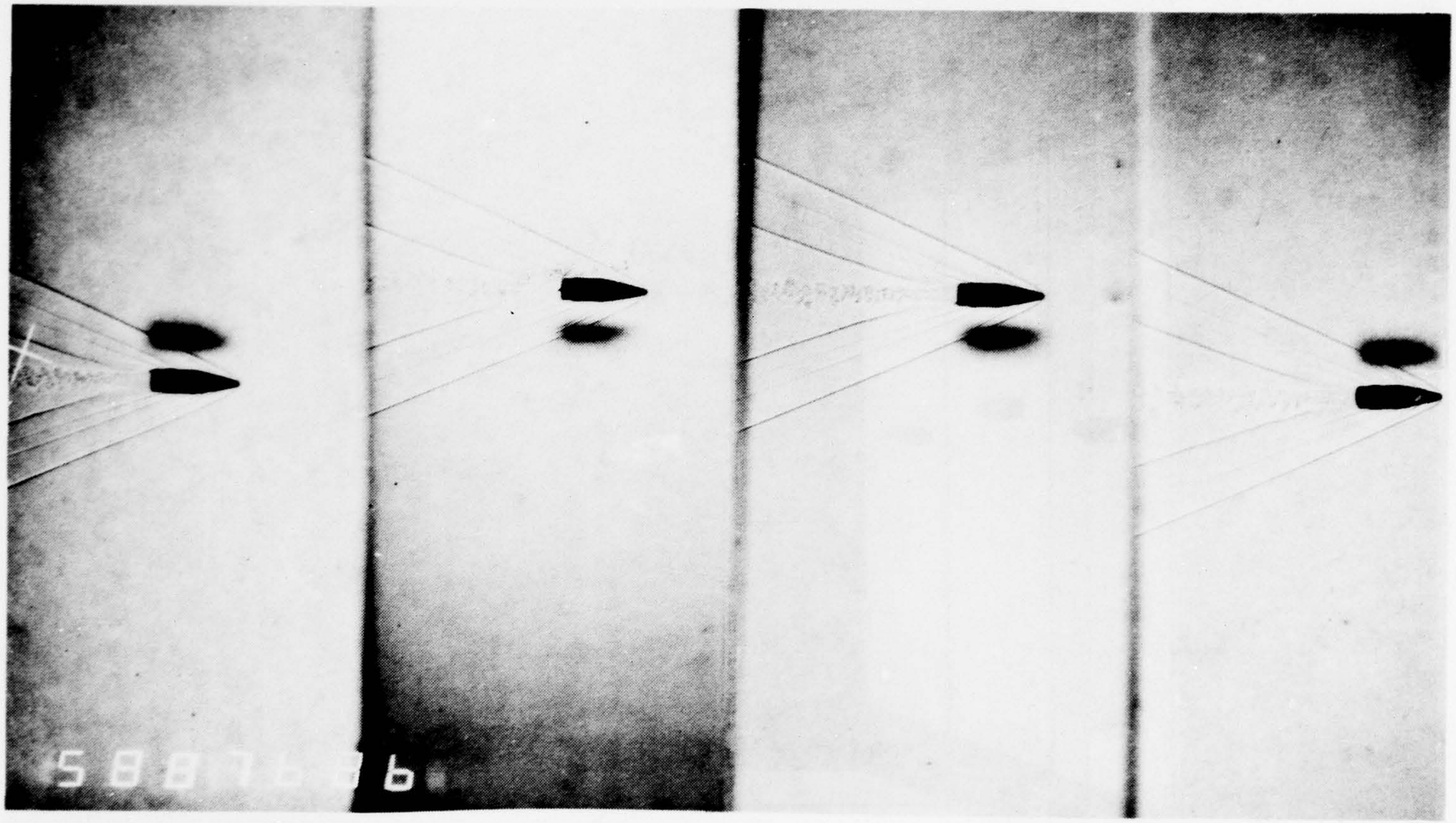


Figure 15. Typical Multiple Spark Shadowgram

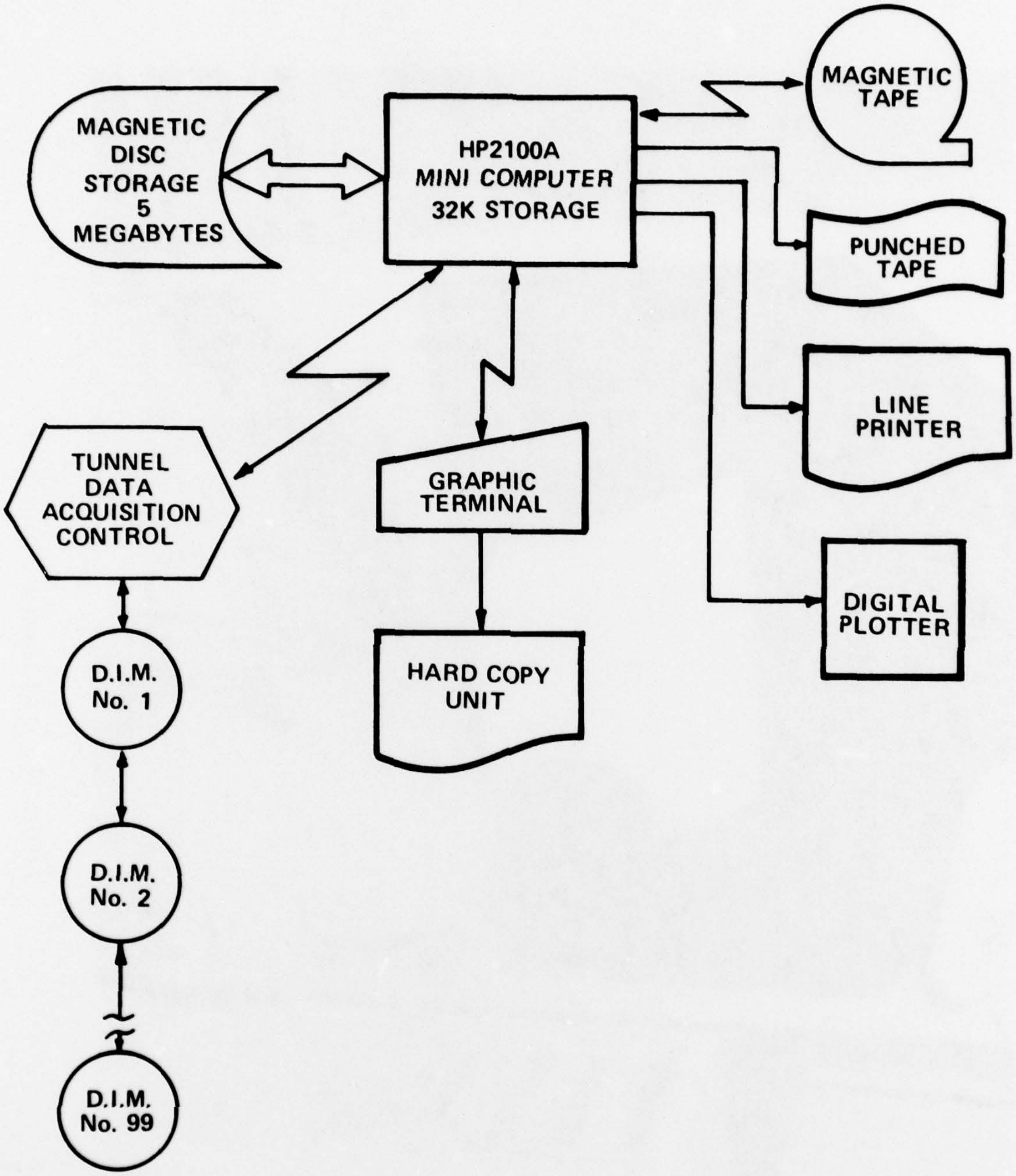


Figure 16. Holophotal Equipment Readiness Monitoring Network (HERMN)

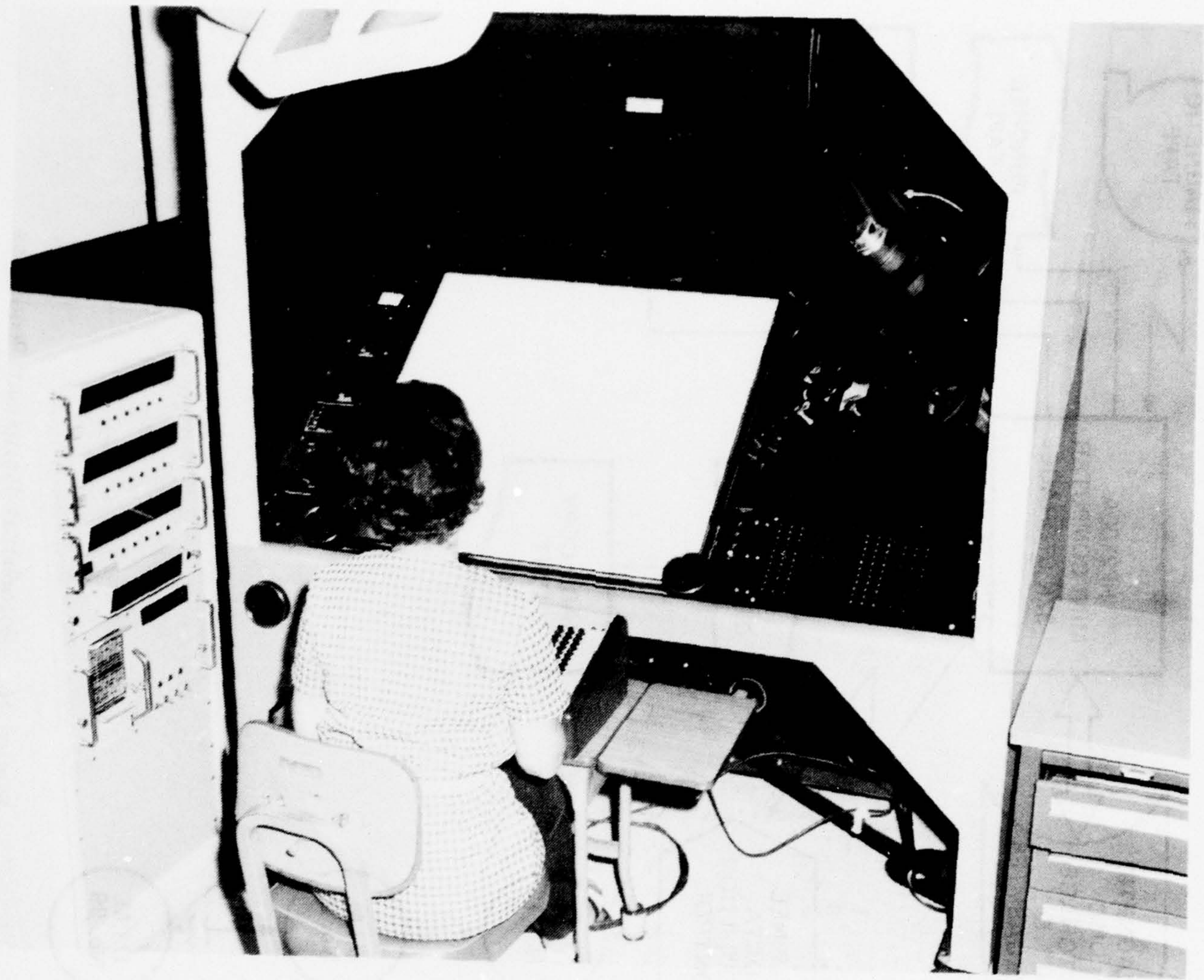
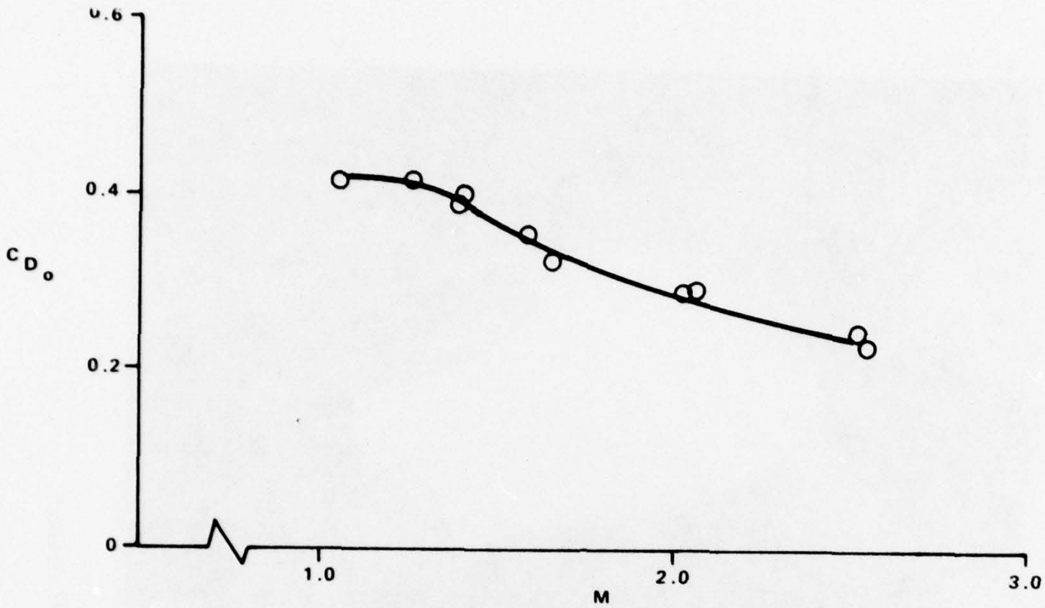
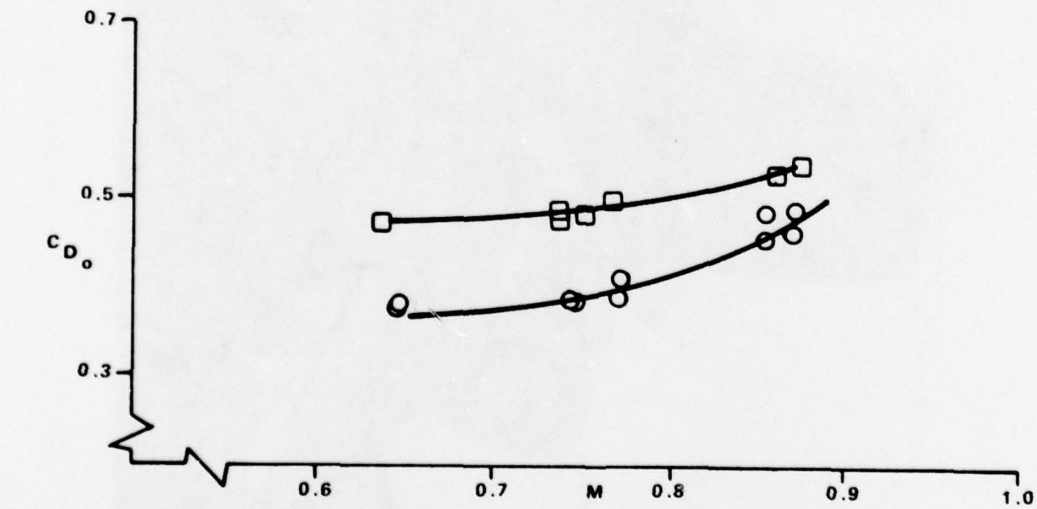


Figure 17. Shadowgraph Telereader

Figure 18. Remote Terminal

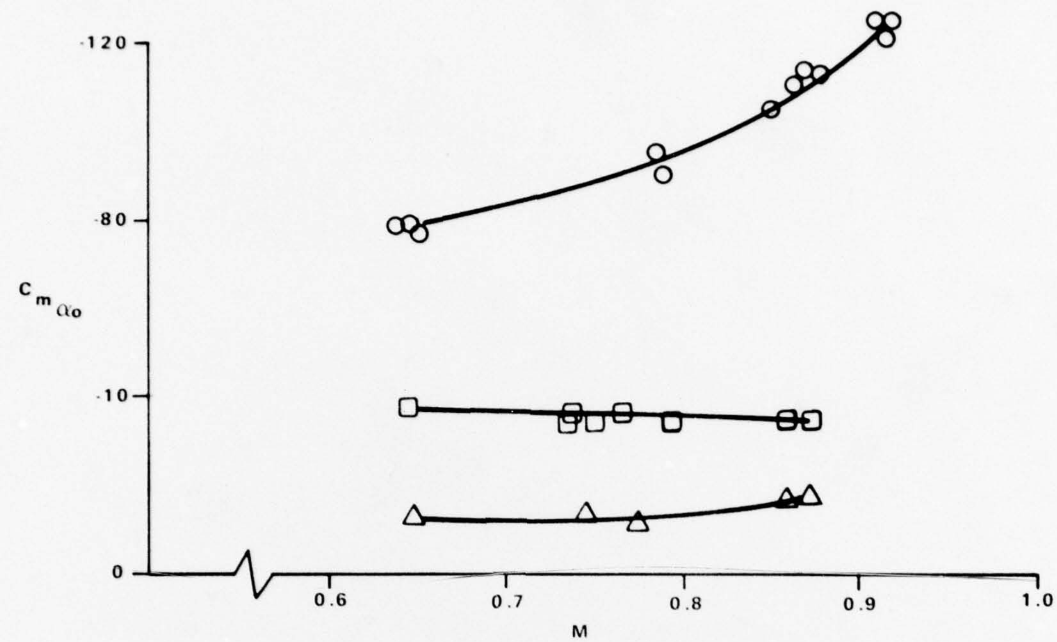


a. CANNON LAUNCHED PROJECTILE

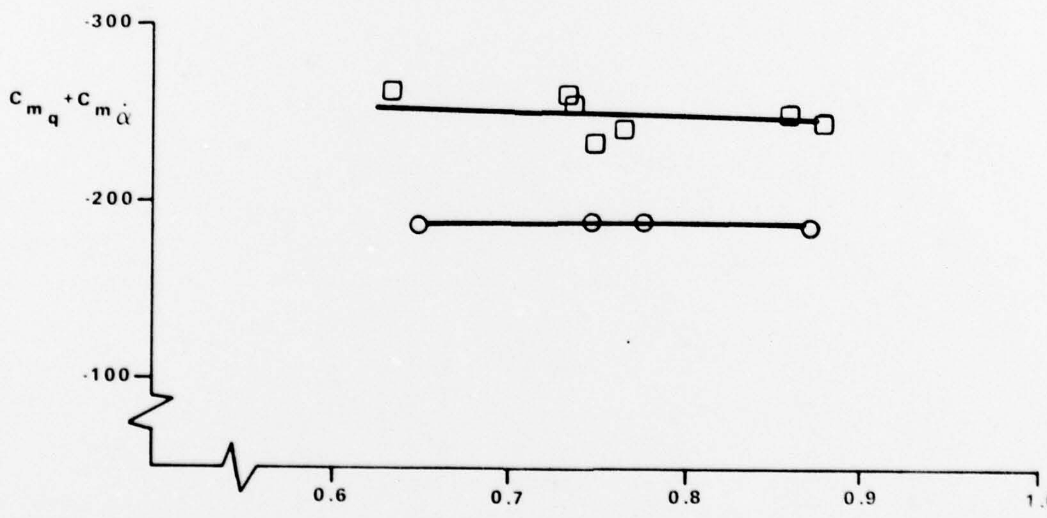


b. TWO FINNED MISSILE CONFIGURATIONS

Figure 19. Typical Drag Data at Zero Angle of Attack



a. STATIC STABILITY DERIVATIVE FOR THREE SUBSONIC MISSILE CONFIGURATIONS



b. DYNAMIC STABILITY DERIVATIVE FOR TWO SUBSONIC FINNED MISSLE CONFIGURATIONS

Figure 20. Typical Stability Data

REFERENCES

1. Parrish, Goldman E., Projectile Measurements and Instrumentation Laboratory Mass Property Measurements, AFATL-TR-74-156, September 1976.

2. West, Kenneth O., Yaw Card Range Tests of a 30mm Target Projectile, AFATL-TR-76-1, January 1976.

3. Sullivan, Judith A. and Cipolla, John R., "A Unique Alignment System," Paper presented at the 26th Meeting of the Aeroballistic Range Association, San Leandro, California, September 30, 1976.

4. Brabham, Clifford, "A Multispark Shadowgraph System for a Free-Flight Aeroballistic Range" Paper presented at International Congress on Instrumentation in Aerospace Simulation Facilities, held at the Royal Military College of Science, Shrivenham, England, September 6 through 8, 1977. Publication No. IEEE 77CH1251-8AES.

5. Murphy, C. H., The Measurement of Nonlinear Forces and Moments by Means of Free-Flight Tests, BRL Report No. 974, 1956.

6. Murphy, C. H., Free-Flight Motion of Symmetric Missiles, BRL Report No. 1216, 1963.

7. Chapman, G. T. and Kirk, D. B., A Method for Extracting Aerodynamic Coefficients from Free-Flight Data, AIAA Journal, Volume 8, No. 4, pp 753-758, April 1970.

8. Whyte, Robert H. and Hathaway, Wayne H., Aeroballistic Range Data Reduction Technique Utilizing Numerical Integration, AFATL-TR-74-41, February 1974.

9. Brunk, James E., User's Manual: Extended Capability Magnus Rotor and Ballistic Body 6-DOF Trajectory Program AFATL-TR-70-40, May 1970.

10. Hathaway, Wayne H. and Whyte, Robert H., Aeroballistic Range Data Analysis for Nonsymmetric Configurations AFATL-TR-76-109, September 1976.

11. Daniel, D. C., Winchenbach, G. L., and Browell, E. V., "The USAF Aeroballistic Research Facility" Paper presented at the 24th Meeting of the Aeroballistic Range Association, Tullahoma, Tennessee, September 18, 1973.

12. Joines, Alfred E. Jr., "Determining Projectile Position and Orientation in the Aeroballistic Research Facility" Computer Sceinces Laboratory, Technology and Project Control Office, Eglin Air Force Base, Florida, 1974.

INITIAL DISTRIBUTION

HQ USAF/RDQRM	1	Univ CA/Librarian	1
HQ USAF/SAMI	1	John Hopkins Univ	1
HQ USAF/XOXFM	1	Iria Erim Lib	1
AFSC/IGFG	1	Inst Defense Anal	1
Directorate/Strike Armament	1	Sandia Lab/Div 1336	1
HQ AFSC/DLCA	1	Rand Corp/LIB-D	1
AFML/DO/AMIC	1	Harry Diamond Labs/AMXDP-TC	1
AFIT/LD	1	DDC-DDA	1
ASD/ENFEA	1	USAFTFWC/TA	1
AFFDL/FES	1	Nav Wpns Lab/Commander	1
TAC/DRAR	1	Watervliet Arsenal	1
HQ SAC/LGWC	1	Plastics Tech Eval Ctr	1
HQ SAC/NRI/Stinfo Lib	1	Nav Wpns Ctr/Code 3123	1
WR-ALC/MMIPDB	1	Honeywell Inc	1
CIA	1	Alpha Rsch Inc	1
AFWL/LR	1	OO-ALC/MMWMP	2
AUL/LSE 71-249	1	AFEWC/EST	1
Redstone Sci Info Ctr/DRDMI-TBD	1	HQ Dept Army/DAMA-WSA	2
US Army Arm Mat Readiness		US Army Arm Rsch & Dev Comd	1
DRSAR-LED	1	Dept Energy Lib	1
US Army Mat Sys Ana		AEDC Lib/Documents	1
DRXSY-PS	1	USA Mat Sys Ana Ag/AMXSY-DS	1
USA Mat Sys Ana Act		US Army Mat Comd/AMCR-YN	1
DRXSY-A	1	Nav Wpns Eval Facility/Code 80	1
US Army Ballistic Rsch Lab		Nav Operations/Chief	1
DRDAR-BLT	1	Nav Rsch Lab/Code 2627	1
US Army Arm Rsch & DLV Comd		CAL Inst Tech/Lib Acquisition	1
DRDAR-TSS #59	1	HQ PACAF/LGWSE	4
Naval Surface Wpns Ctr/Code G-14	1	USAFTAWC/TX	1
Naval Surface Wpns Ctr	2	AFATL/DL	1
Nav Ord Stn/Tech Lib	1	AFATL/DLY	1
Nav Wpns Stn/Code 2034	2	AFATL/DLOU	1
Nav Underwater Sys Ctr		HQ USAFE/DOQ	1
Code 54/Tech Lib	1	HQ PACAF/DOOFQ	2
Info Sci Div/Code 233	1	IPAC/Library	2
Sys Dev Dept/Code 31	1	ASD/XRP	1
AFWL/SUL	1	USA Tradoc Sys Ana Act	1
Nav Air Sys Comd/Code Air-5323	1	HQ TAC/INAT	1
Office Naval Rsch	1	AFATL/DLODL	2
Univ CA/Chem Dept	1	AFATL/DLYV	1
Lawrence Livermore Lab/L-324	1	AFATL/DLDL	100

INITIAL DISTRIBUTION (Concluded)

AFATL/DLDE	1
AFATL/DLDA	1
AFATL/DLDG	5
AFIS/INT	1
Lawrence Livermore Lab	3
Mason & Hanger-Silas Mason Co	2
US Army Arm Rsch & Dev Comd	2
Nav Sea Sys Comd	2
NSWC/Nav Ord Lab	1
NSWC/White Oak Lab	2
HQ AFLC/Low	1
ASD/ENESH / S. Johns	1
AFATL/DLJ	2
AFATL/DLA	1
ADTC/SDC	1
AFATL/DLJK	2
AEDC	2
General Electric	2
ARADCOM	3
COMIPAC/I-232	1
AFATL/DLB	1
AFATL/DLM	1
AFATL/DLD	1
ADTC/XRB	1
AFATL/DLYD	1
AFATL/DLYW	1
AFATL/DLJA	1
AFATL/DLJW	1
AFATL/DLJC	1
AFATL/DLMA	1
AFATL/DLJF	1
AFATL/DLMM	1
AFATL/DLMI	1
AFATL/DLMT	1
ADTC/SDE	1
ADTC/SD15	1
ADTC/SD9	1
ADTC/SD7	1
ADTC/SD102	1
ADTC/SD3	1
ADTC/SD20	1
ADTC/XRC	1
ADTC/XRG	1
ADTC/XRL	1
ADTC/XRP	1
ADTC/XRS	1